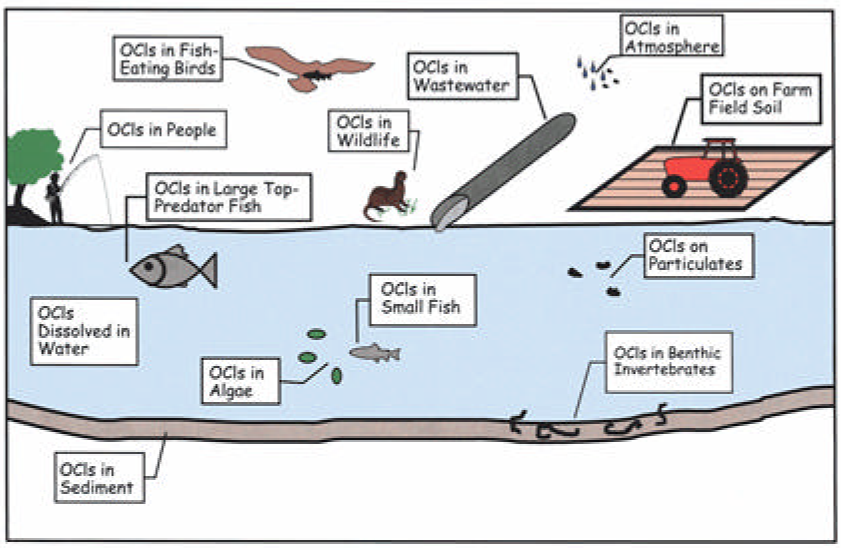
CALIFORNIA WATER INSTITUTE

Report TP 02-06

Organochlorine Pesticide, PCB and Dioxin/Furan Excessive Bioaccumulation Management Guidance

Conceptual Model of OCl Bioaccumulation



Prepared by
G. Fred Lee, PhD, DEE and Anne Jones-Lee, PhD
California Water Institute
California State University, Fresno

for the
Central Valley Regional Water Quality Control Board
Sacramento, California

and the
State Water Resources Control Board
Sacramento, CA

December 2002

DISCLAIMER

This publication is a technical report by staff of the California Water Institute to the California State Water Resources Control Board and the Regional Water Quality Control Board, Central Valley Region. No policy or regulation is either expressed or intended.

Disclosure Statement

Funding for this project has been provided in part by the U.S. Environmental Protection Agency (US EPA) pursuant to Assistance Agreement No. C9-989268-99-0 and any amendments thereto which has been awarded to the State Water Resources Control Board (SWRCB) for the implementation of California's Nonpoint Source Pollution Control Program. The contents of this document do not necessarily reflect the views and policies of the US EPA or the SWRCB, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. State funding was used for the Total Maximum Daily Load (TMDL)-related report prepared pursuant to this project (SWRCB Agreement #00-219-150-0).

This project was conducted by Drs. G. Fred Lee and Anne Jones-Lee as employees of the California Water Institute, California State University, Fresno. In addition to the support provided to this project by the California Water Institute and the Central Valley Regional Water Quality Control Board, it was supported by G. Fred Lee & Associates, El Macero, California.

Acknowledgment

We wish to acknowledge the assistance provided in developing this report by Les Grober, Jerrold Bruns, Lori Webber and Kelly Briggs of the Central Valley Regional Water Quality Control Board staff; Dr. Val Connor, formerly with the Central Valley Regional Water Quality Control Board now with the State Water Resources Control Board; and William Jennings (the DeltaKeeper). We also wish to acknowledge the assistance of Mary McClanahan of the California Water Institute, California State University, Fresno.

California Water Institute
California State University, Fresno

The California Water Institute was started with seed money provided by the Proposition 13 Water Bond Measure, approved by voters in 2000. The Institute is housed at the California State University, Fresno.

The goal of the Institute is to provide a place where agricultural, urban, and environmental interests can be brought together in an unbiased, open, collaborative process to develop a shared vision of how to best utilize our water resources. It is the stated purpose of the Institute to work on collaborative solutions to pressing water issues facing the State. The staff of the Institute includes economists, chemists, crop water usage specialists, resource specialists, and environmental engineers. In addition, faculty at the California State University, Fresno, collaborate with the Institute in important research efforts.

Preface

There are 11 waterbodies in the Central Valley that in 1998 were determined to be Clean Water Act 303(d) "impaired" due to excessive bioaccumulation of organochlorine (OCl) "Group A" pesticides (such as toxaphene, chlordane, dieldrin, aldrin, endrin, heptachlor, heptachlor epoxide, hexachlorocyclohexane [including lindane], and endosulfan); DDT, DDE, and DDD. These pesticides are called legacy pesticides, since they were banned from use several decades ago because of their long-term persistence in the environment, their adverse impacts to aquatic life and wildlife, especially to fish-eating birds, and their potential to cause cancer in people who ingest food residues of them. In addition, polychlorinated biphenyls (PCBs); dioxins/furans are of concern since they cause 303(d) listing of some Central Valley waterbodies. This group of OCl chemicals tends to bioaccumulate in the edible tissue of fish. The waterbodies impacted include Delta Waterways, Lower American River, Colusa Basin Drain, Lower Feather River, Lower Merced River, Natomas East Main Drain, San Joaquin River, Lower Stanislaus River, Stockton Deep Water Ship Channel, Lower Tuolumne River, and Lower Kings River. Further, studies conducted since 1998 show that there are other waterbodies in the Central Valley, such as the Sacramento River, which contain fish that have bioaccumulated excessive levels of organochlorine pesticides and PCBs that are not now on the 303(d) list but could be added to this list, based on information available.

The excessive bioaccumulation of the OCls in some of the fish taken from these waterbodies represents a threat to cause cancer in those who consume these fish on a regular basis. This situation caused the Central Valley Regional Water Quality Control Board (CVRWQCB) to list these waterbodies as 303(d) impaired, which necessitates that a TMDL be developed to control the excessive bioaccumulation of the OCls that are occurring above recommended health threat levels in edible fish tissue. US EPA Region 9 has made funds available to the CVRWQCB/SWRCB to support the development of a technical TMDL that would lead to the control of the OCls that are bioaccumulating to excessive levels in Central Valley waterbody fish.

A contract was developed between the State Water Resources Control Board and the California Water Institute at California State University, Fresno, to develop a organochlorine pesticide and PCB TMDL report. Dr. G. Fred Lee and Dr. Anne Jones-Lee, as employees of the California Water Institute, undertook the development of this report. As part of the development of the scope of work for this effort, it was concluded by the CVRWQCB staff that there is insufficient information to proceed with an organochlorine pesticide bioaccumulation TMDL report. It was determined, however, that there was need to compile and critically review the information that would be necessary for such a report, and develop guidance on the approach that should be used to develop the needed information so that when it is available, a TMDL to control the excessive bioaccumulation of the organochlorine pesticides and PCBs, dioxins/furans could be developed. This report presents a review of the available information pertinent to managing OCl excessive bioaccumulation and provides guidance on filling the information gaps to complete a TMDL technical report for the organochlorine pesticides, PCBs, dioxins/furans.

Work on the occurrence, fate, transport, and effects of organochlorine pesticides and PCBs is a topic on which Dr. G. Fred Lee, senior author of this report, has been conducting research since the early 1960s, while teaching at the University of Wisconsin, Madison, where he established and directed the graduate degree program in Water Chemistry. He, with his graduate students, conducted extensive research on this topic in the 1960s, and subsequently at the University of Texas, Dallas, in the 1970s. During the mid- to late 1990s, the authors of this report conducted studies in cooperation with the Santa Ana Regional Water Quality Control Board on the organochlorine pesticides in fish taken from Upper Newport Bay and its tributaries, located in Orange County, California. The Upper Newport Bay OCl excessive bioaccumulation situation led to the Bay and its tributaries being listed by the Santa Ana Regional Water Quality Control Board as 303(d) "impaired," which requires that a TMDL be developed to control the excessive bioaccumulation. A TMDL for control of excessive bioaccumulation of the OCls in the Upper Newport Bay watershed has been developed by US EPA Region 9.

This OCl management guidance report for controlling excessive bioaccumulation of OCls in Central Valley waterbody fish includes information derived from a city of Stockton Smith Canal sediment bioaccumulation study report that the authors, with the assistance of Scott Ogle of Pacific EcoRisk, developed in July 2002. The Smith Canal sediment PCB pilot study was funded by US EPA 319(h) funds, and the Central Valley Regional Water Quality Control Board, with support by Pacific EcoRisk, DeltaKeeper, and G. Fred Lee & Associates. It was the first of this type of study conducted in the Central Valley and possibly the State, concerned with bioavailability of organochlorine pesticides and PCBs in sediments.

It has been known for many years that the total concentrations of these chemicals in sediments are an unreliable indicator of the potential for them to bioaccumulate in benthic organisms or higher-trophic-level organisms. It has been established that total organic carbon in sediments determines to some extent the bioavailability of these pesticides and PCBs. To address this issue, the US EPA developed a standard bioaccumulation test, using the oligochaete (worm) *Lumbriculus variegatus* as a test organism that could be used to determine if the sediment-associated PCBs and organochlorine pesticides are bioavailable. The Smith Canal pilot study proved to be of value in demonstrating that the US EPA standard bioaccumulation test could readily be implemented to determine bioavailability of PCBs and OCl pesticides in sediments. With modification it can also be used to determine the potential for bioaccumulation of OCls associated with soil particles that are transported to waterbodies.

A review of the literature shows that there is considerable unreliable information on managing excessive bioaccumulation of OCls in edible fish. This report presents guidance on the development of technically valid management of OCls in fish tissue that is based on the senior author's experience and expertise having worked on this topic for about 40 years.

G. Fred Lee, PhD, DEE
Anne Jones-Lee, PhD

Executive Summary

There are 11 waterbodies in the Central Valley that have been found to contain excessive concentrations of Group A pesticides, DDT, PCBs and/or dioxins/furans. These include the Delta Waterways (DDT, Group A Pesticides), Lower American River (Group A Pesticides), Colusa Basin Drain (Group A Pesticides), Lower Feather River (Group A Pesticides), Lower Merced River (Group A Pesticides), Natomas East Main Drain (PCBs), San Joaquin River (DDT, Group A Pesticides), Lower Stanislaus River (Group A Pesticides), Stockton Deep Water Ship Channel (Dioxins, Furans, PCBs), Lower Tuolumne River (Group A Pesticides), and Lower Kings River (Toxaphene). These waterbodies are referred to in this report as "Waterbodies." The Group A pesticides include aldrin, dieldrin, chlordane, endrin, heptachlor, heptachlor epoxide, hexachlorocyclohexane (including lindane), endosulfan, and toxaphene. In addition, there is concern about excessive bioaccumulation of DDT, polychlorinated biphenyls (PCBs), and dioxins/furans. These pesticides, PCBs and dioxins are referred to herein as "OCls."

Some fish taken from the Waterbodies of concern in this OCl bioaccumulation management guidance report have been found to contain sufficient concentrations of one or more Group A pesticides, DDT, PCBs, and/or dioxins/furans to be a threat to cause cancer in those who use these fish as food. The beneficial uses of these Waterbodies include freshwater habitat. The excessive bioaccumulation of the OCls in edible fish impairs this use. It may also be adverse to aquatic life and waterbody-associated terrestrial life resources.

Each of the Waterbodies of concern in this OCl excessive bioaccumulation management guidance report has received in the past (and may receive, to some extent, today) sufficient concentrations of one or more OCls to lead to concentrations of these chemicals in some of the Waterbodies' fish to be above the California Office of Environmental Health Hazard Assessment (OEHHA) guidelines for the use of the fish as food. The former use of one or more of the OCls (except dioxins/furans) in each of the Waterbodies' watersheds for agricultural and/or urban purposes has led to stormwater runoff transport and, in some instances, wastewater discharges of the OCl(s) to a sufficient extent to lead to bioaccumulation to excessive levels in some of the Waterbodies' receiving the runoff/discharges edible fish. With respect to dioxins and furans, they may have been discharged to the Waterbody or its tributary from former municipal and/or industrial wastewater discharges as well as in stormwater runoff from highways and streets and/or runoff/discharges from areas where low-temperature burning has taken place. They may also have been contaminants in the herbicide 2,4,5-T and could be derived from areas where this herbicide has been used.

The Waterbodies are listed on the federal Clean Water Act's 303(d) list as "impaired" for Group A pesticides, DDT, PCBs, and/or dioxins/furans. The impairment extends throughout the Waterbody and possibly into its tributaries. The 303(d) listing requires development of a Total Maximum Daily Load (TMDL) for the OCl(s) of concern for the listed Waterbodies. The information provided in this OCl management guidance report is designed to be of assistance in developing a TMDL to control excessive OCl bioaccumulation in Central Valley Waterbody fish and other aquatic life.

Each of the Waterbodies' watersheds has its own characteristics and specific sources of the OCls of concern. At this time, specific information on the former activities in each Waterbody's watershed that contributed OCls that have bioaccumulated to excessive levels in fish in the Waterbody is not available. While there are residues of these OCls in soils and possibly waste deposits within the Waterbodies' watersheds that are now continuing to contribute the OCl(s) of concern for that Waterbody to the Waterbody, the most likely current source of the OCl residues in edible fish is the Waterbody's sediments. Aquatic sediments are known to be major "sinks" (storage reservoirs) for the OCls that can, under some conditions, be a source of OCls through the food web for higher-trophic-level organisms that are used as human food. While the focus of this report is to control excessive bioaccumulation of OCls that are a threat to the use of certain fish as food, there is also concern about the potential impacts of OCl residues on higher-trophic-level aquatic organisms and terrestrial organisms, including birds, which acquire OCls through the consumption of aquatic life.

There have been no studies which provide information on the amounts of the OCls contributed to each of the listed Waterbodies from its watershed that are now causing excessive bioaccumulation of one or more of the OCls in the Waterbodies' edible fish. Also, there have been limited studies of the current OCl residues in some of the Waterbodies' sediments which could be serving as a reservoir for excessive bioaccumulation in edible fish. Basically, the situation is one of finding excessive levels of one or more OCls in a Waterbody's edible fish which can likely be attributed to the former use of these chemicals in the Waterbody's watershed. Since many of the Group A pesticides, DDT and PCBs have not been legally used in the Waterbody's watershed for at least one, and for some chemicals, several decades, it is possible that there are no external (to the Waterbody) sources that are significantly contributing to the current Waterbody's sediment reservoir of the OCls that are leading to excessive bioaccumulation in fish. However, as discussed herein, there are areas within the Central Valley where there is sufficient transport of OCls from agricultural lands to be a potentially significant source of OCls leading to their excessive bioaccumulation in downstream waterbody fish. There is also potential for domestic wastewaters to be a current source of OCls that are leading to excessive bioaccumulation of the OCls in receiving-water fish.

There are a variety of factors that influence how OCls in water, soils, or sediments are transported in a waterbody's watershed to a waterbody, and that control the bioaccumulation of the OCl residues in edible fish. One of the more important factors is the total organic carbon of the sediments. Sediments with higher organic carbon tend to reduce the bioavailability of sediment-associated OCls.

Bioaccumulation of OCls in fish depends on the size (length), age, type and lipid content of the fish. The OCl monitoring of fish tissue that has been conducted in the Central Valley since the late 1970s has not provided a sufficient database to critically examine the factors that can influence the OCl tissue residues in Central Valley fish. Future monitoring needs to include assessment of the OCl residues in various types of fish that are used as human food.

There are several management goals that can be used for controlling excessive OCl bioaccumulation, the most important of which are the OEHHA screening values (Table 4) for determining excessive edible fish tissue concentrations for each of the OCls of concern in this guidance. Also, the California Toxics Rule criteria (Table 2) and the US EPA and OEHHA drinking water MCLs (Table 3) are appropriate management goals to control excessive concentrations of OCls in waterbodies.

In developing a management goal for the OCls, it is suggested that the US EPA recommended approach of using the management goal as the allowable loading capacity (concentration) for the Waterbody be used. This approach focuses on achieving an acceptable edible fish tissue OCl residue concentration. Ultimately, it will be necessary to develop a site-specific biota sediment accumulation factor for each listed Waterbody and each OCl of concern for that Waterbody in order to relate current sediment sources of the chemical leading to excessive bioaccumulation to current OCl tissue residues. This approach can ultimately lead to defining the degree of sediment remediation and current watershed source control needed to eliminate the excessive bioaccumulation of the OCl in a particular Waterbody.

Table of Contents

Table of Contents (continued)

Table of Contents (continued)

List of Tables

List of Figures

List of Figures (continued)

List of Acronyms and Abbreviations

303(d) List	Clean Water Act 303(d) List of Impaired Waterbodies
§	Section (as in a law or regulation)
Σ	Sum
a.i.	Active ingredient of a pesticide
ATSDR	U.S. Agency for Toxic Substances and Disease Registry
BAF	Bioaccumulation factor
Basin Plan	Water Quality Control Plan (Basin Plan) Central Valley Region ; Sacramento River and San Joaquin River Basins
BCF	Bioconcentration factor
bwt	Body weight
CCC	Criterion Continuous Concentration
CDFG	California Department of Fish and Game
CMC	Criterion Maximum Concentration
CTR	California Toxics Rule
CV	Coefficient of variation
CVRWQCB	Central Valley Regional Water Quality Control Board
CWA	Federal Clean Water Act
CWC	California Water Code
total DDT	DDT + DDE+ DDD
Delta	Sacramento-San Joaquin Delta
DPR	California Department of Pesticide Regulation
DWR	California Department of Water Resources
GLWQI	Great Lakes Water Quality Initiative Final Rule
K_{OC}	Equilibrium constant, normalized for organic carbon
K_{OW}	Octanol Water Partition Coefficient
LA	Load allocation
LC	Loading capacity
LC_{50}	Lethal concentration which kills 50 percent of test organisms in a given period of time
LOAEL	Lowest observable adverse effect level
LOQ	Limit of quantification
MCL	Maximum contaminant level
MOS	Margin of safety
NAWQA	National Water-Quality Assessment (program by the USGS)
NOEC	No observed effect concentration

List of Acronyms and Abbreviations

NWIS	National Water Information System
OCls	Group A Pesticides [aldrin, dieldrin, chlordane, endrin, heptachlor, heptachlor epoxide, hexachlorocyclohexane (including lindane), endosulfan, and toxaphene], DDT, Polychlorinated Biphenyls (PCBs), Dioxins, Furans
OEHHA	Office of Environmental Health Hazard Assessment
OP	Organophosphate
PAHs	Polynuclear Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
Porter-Cologne or Porter-Cologne Act	Porter-Cologne Water Quality Control Act as amended
PUR	Pesticide Use Report
RfD	Reference dose
SARWQCB	Santa Ana Regional Water Quality Control Board
SJR	San Joaquin River
State Board or SWRCB	California State Water Resources Control Board
SWDB	Surface Water Database
TIE	Toxicity Identification Evaluation
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TSMP	Toxic Substance Monitoring Program (SWRCB)
TUa	Toxic Units, Acute
UCIPM	University of California Statewide Integrated Pest Management Project
USDA	United States Department of Agriculture
US EPA	United States Environmental Protection Agency
USFDA	U.S. Food and Drug Administration
USGS	United States Geological Survey
Waterbodies	Delta Waterways, Lower American River, Colusa Basin Drain, Lower Feather River, Lower Merced River, Natomas East Main Drain, San Joaquin River, Lower Stanislaus River, Stockton Deep Water Ship Channel, Lower Tuolumne River, and Lower Kings River
WLA	Waste Load Allocation
WDRs	Waste Discharge Requirements

Units of Measure

µg	microgram
µg/g	micrograms per gram
µg/L	micrograms per liter (0.10 µg/L = 100 ng/L)
µm	micrometer
cm	centimeter
g	gram
g/day	grams per day
g/L	grams per liter
in	inch
kg	kilogram
L	liter
lbs	pounds
m	meter
mg	milligram
mg/g	milligrams per gram
mL	milliliter
mm	millimeter
mPa	milliPascals
ng	nanograms
ng/L	nanograms per liter (100 ng/L = 0.10 µg/L)
ppb	parts per billion, µg/kg
ppm	parts per million, mg/kg or µg/g
ppt	parts per trillion, ng/kg

Organochlorine Compounds of Interest

Common Name	Chemical Name
Aldrin	(1a, 4a, 4aß, 5a, 8a, 8aß) 1,2,3,4,10,10–hexachloro–1,4,4a,5,8,8a-hexahydro-1,4:5,8-dimethanonaphthylene
?-BHC (?-HCH)	1a,2a,3ß,4a,5a,6ß-hexachlorocyclohexane, gamma isomer
Chlordane	1,2,4,5,6,7,8,8-octachloro-3a,4,7,7a-tetrahydro-4,7-methanoindan
DDD	1,1-dichloro-2,2-bis(*p*-chlorophenyl) ethane
DDE	dichloro diphenyl dichloroethylene
DDT	dichloro diphenyl trichloroethane
Dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro (endo,exo) 1,4:5,8-dimethanonaphthalene
Dioxin	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
Endosulfan	6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepin-3-oxide
Endrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-(endo,endo)-1,4:5,8-dimethanonaphthalene
Heptachlor	1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methano-1*H*-indene
Heptachlor epoxide	2,3,4,5,6,7,8-heptachloro-1a,1b,5,5a,6,6a-hexahydro-2,5-methano-2*H*-indeno(1,2b)oxirene
Lindane	see ?-BHC
PCB	polychlorinated biphenyls, sum of the chlorinated biphenyls whose analytical characteristics resemble those of Aroclor-1016, 1221, 1232, 1242, 1248, 1254, and 1260
2,3,7,8 - TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
Toxaphene	polychlorinated camphene (67-69% chlorine); camphene = 2,2-dimethyl-3-methylenebicyclo-[2.2.1]heptane; 2,2-dimethyl-3-methylenenorbornane

Source: Larson, *et al*. (1997) and Cheng (1990)

TCDD Equivalents shall mean the sum of the concentrations of chlorinated dibenzodioxins (2,3,7,8-CDDs) and chlorinated dibenzofurans (2,3,7,8-CDFs) multiplied by their respective toxicity factors, as shown in the table below.

Isomer Group	Toxicity Equivalence Factor
2,3,7,8-tetra CDD	1.0
2,3,7,8-penta CDD	0.5
2,3,7,8-hexa CDDs	0.1
2,3,7,8-hepta CDD	0.01
octa CDD	0.001
2,3,7,8 tetra CDF	0.1
1,2,3,7,8 penta CDF	0.005
2,3,4,7,8 penta CDF	0.5
2,3,7,8 hexa CDFs	0.1
2,3,7,8 hepta CDFs	0.01
octa CDF	0.001

Source: SWRCB, California Ocean Plan (1998a)

Organochlorine Pesticide, PCB and Dioxin/Furan Excessive Bioaccumulation Management Guidance

Introduction

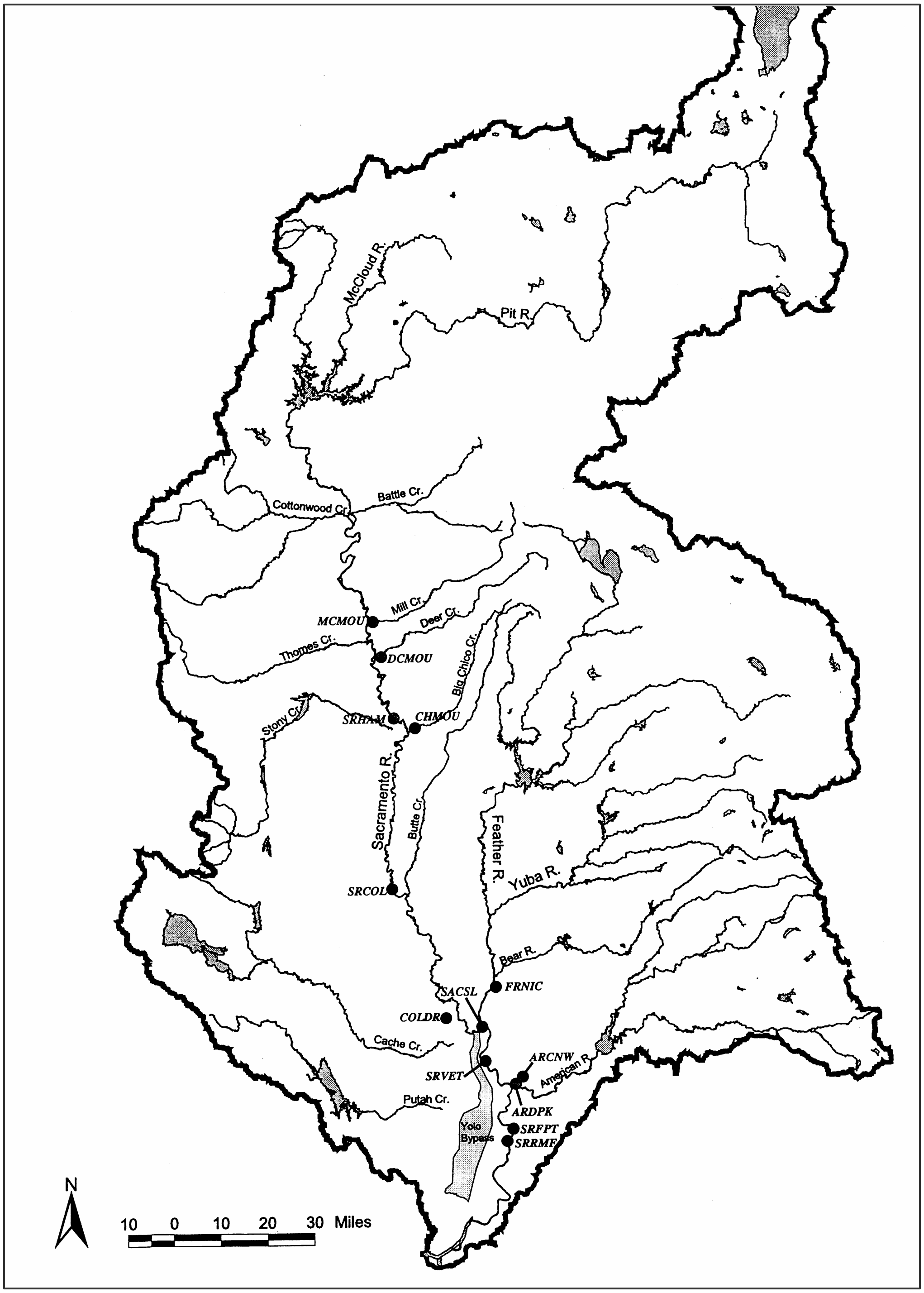
The Delta Waterways, Lower American River, Colusa Basin Drain, Lower Feather River, Lower Merced River, Natomas East Main Drain, San Joaquin River, Lower Stanislaus River, Stockton Deep Water Ship Channel, Lower Tuolumne River, and Lower Kings River (referred to herein as Waterbodies) are listed on the federal Clean Water Act's 303(d) list as "impaired" for organochlorine (OCl) compounds, including "Group A" pesticides (such as toxaphene, chlordane, dieldrin, aldrin, endrin, heptachlor, heptachlor epoxide, hexachlorocyclohexane [including lindane], and endosulfan); DDT, DDE, DDD, and the non-pesticides polychlorinated biphenyls (PCBs), dioxins/furans (SWRCB, 1998b). The water quality problem caused by these chemicals is excessive bioaccumulation of one or more of the OCls in edible fish tissue compared to public health screening values established to protect humans from an increased risk of cancer associated with using the fish as food.

The impairment may extend throughout the Waterbodies and possibly into the Waterbodies' tributaries. The 303(d) listing requires development of a Total Maximum Daily Load (TMDL) for the OCl(s) that have bioaccumulated to excessive levels in one or more types of Waterbody fish. As established in 1998, these TMDLs are to be initiated in January 2004 and be completed by December 2011. This timeframe allows adequate time to develop the needed information discussed herein, provided that funding to support this effort is achieved in the near future.

This OCl excessive bioaccumulation management guidance has been developed to compile and review the existing information needed to develop a technically valid management plan. It also defines the locations and topic areas where additional information is needed to develop a TMDL for managing excessive bioaccumulation of the OCls in listed Waterbodies.

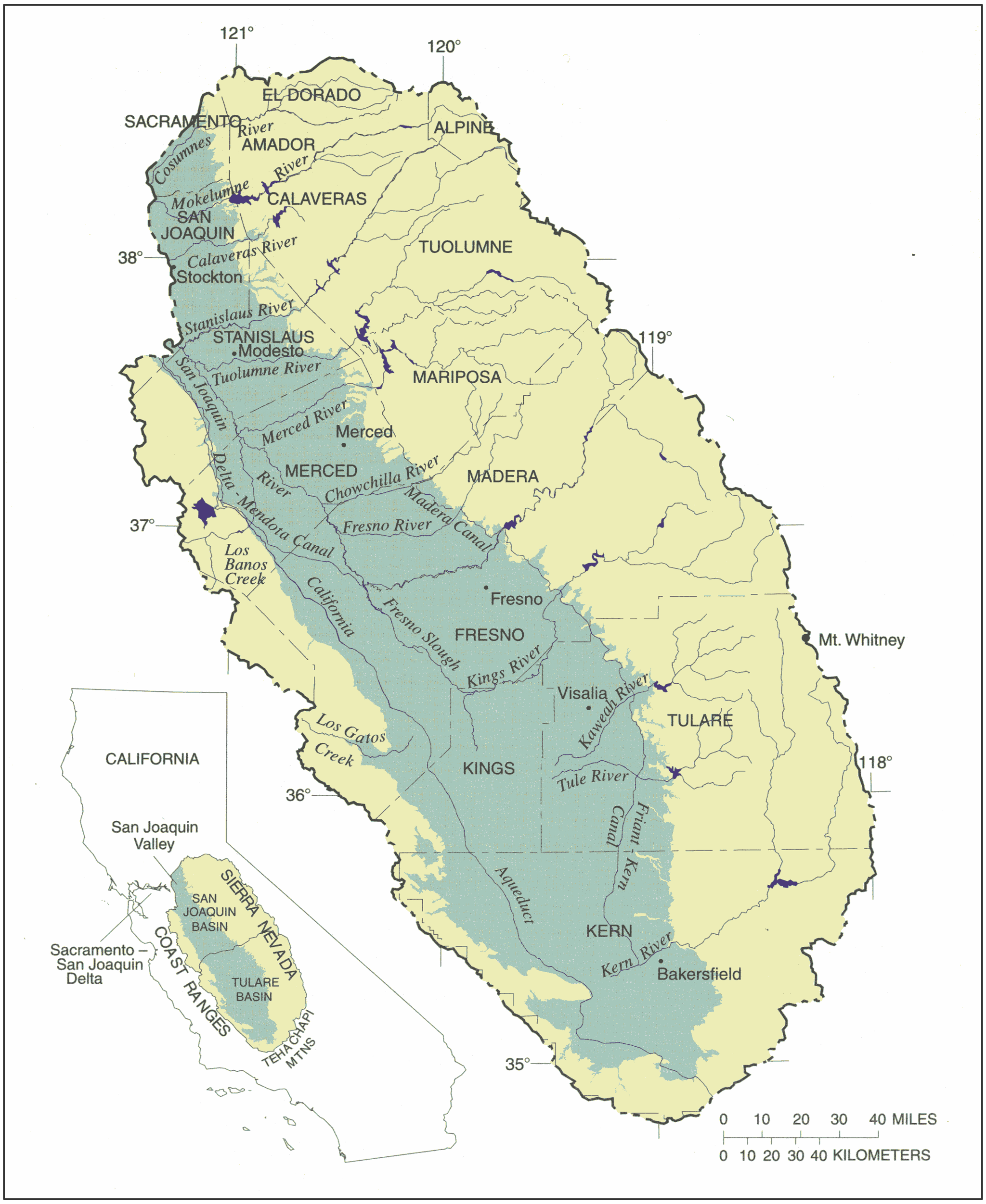
Figures 1(a) through 1(k) present a set of maps of the Central Valley of California, showing the Waterbodies that are listed as 303(d) impaired because of excessive bioaccumulation of OCls in edible fish tissue. These figures also show the locations that have been sampled for OCls in fish, other organisms, sediments and/or water. The data obtained in these studies are presented in Appendices C and D. The data spreadsheets presented in these appendices have associated with each data entry an investigator code letter that can be tied back to the maps of the study areas presented in Figures 1(a) through 1(k).

Figure 1(a)
Pesticide Monitoring Locations for the
Sacramento River Watershed Program, 2000-2001
(Appendix C, Data set code b)



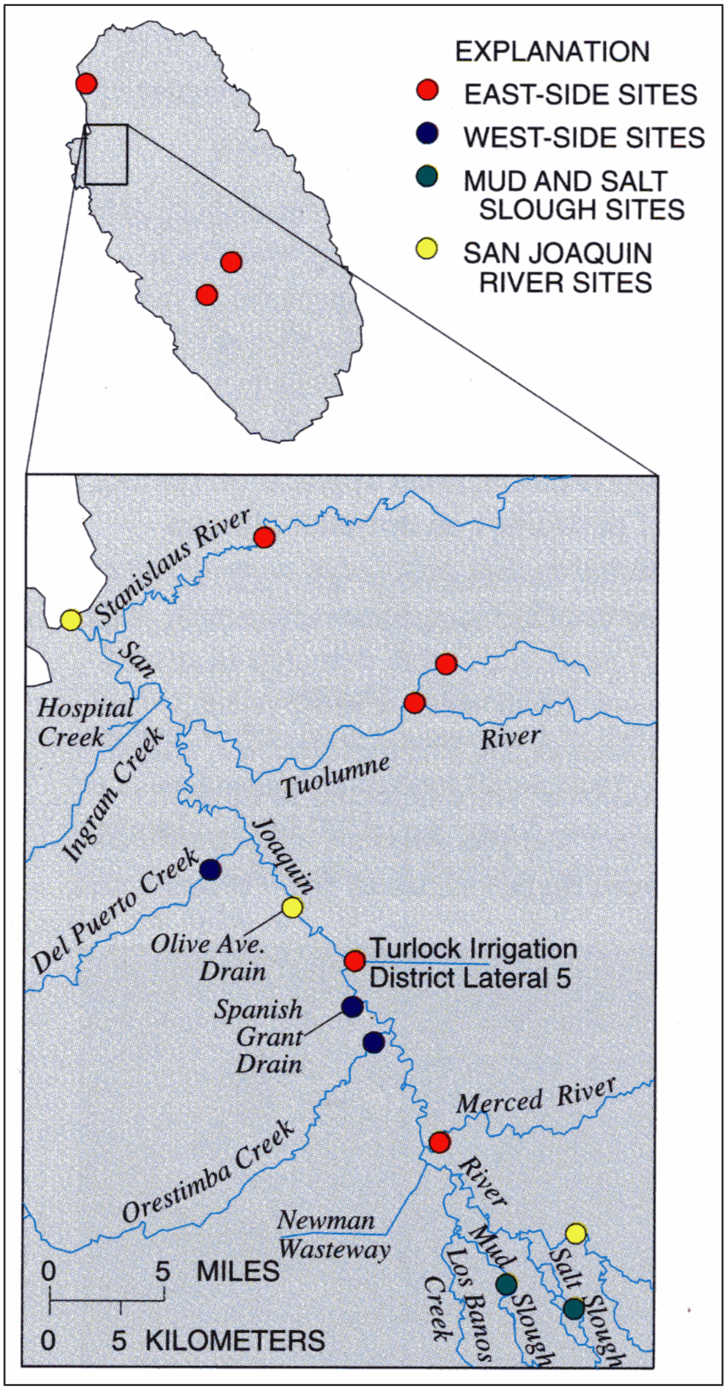
Source: LWA (2002)

Figure 1(b)
San Joaquin—Tulare Basins, California
(Appendix C, Data set code e)



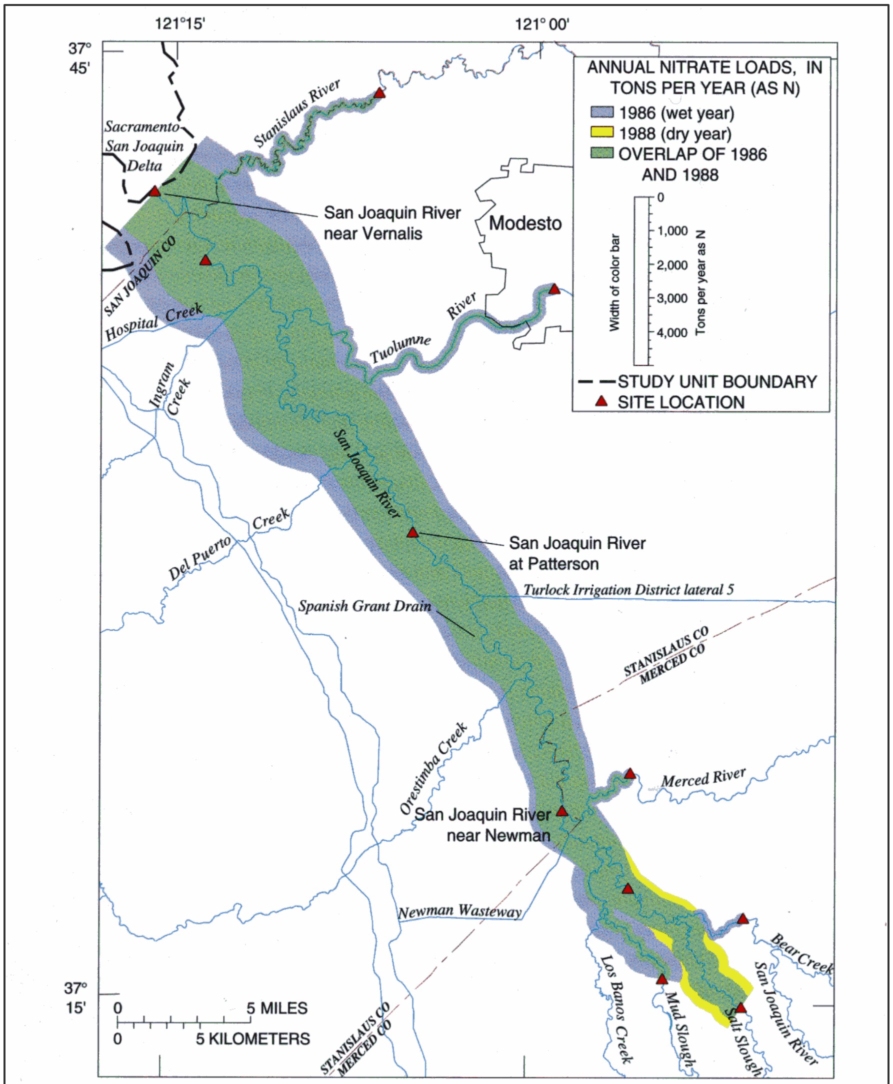
Source: Gronberg, *et al*. (1998)

Figure 1(c)
USGS Sampling Sites
(Appendix C, Data set code e)



Source: Dubrovsky, *et al*. (1998)

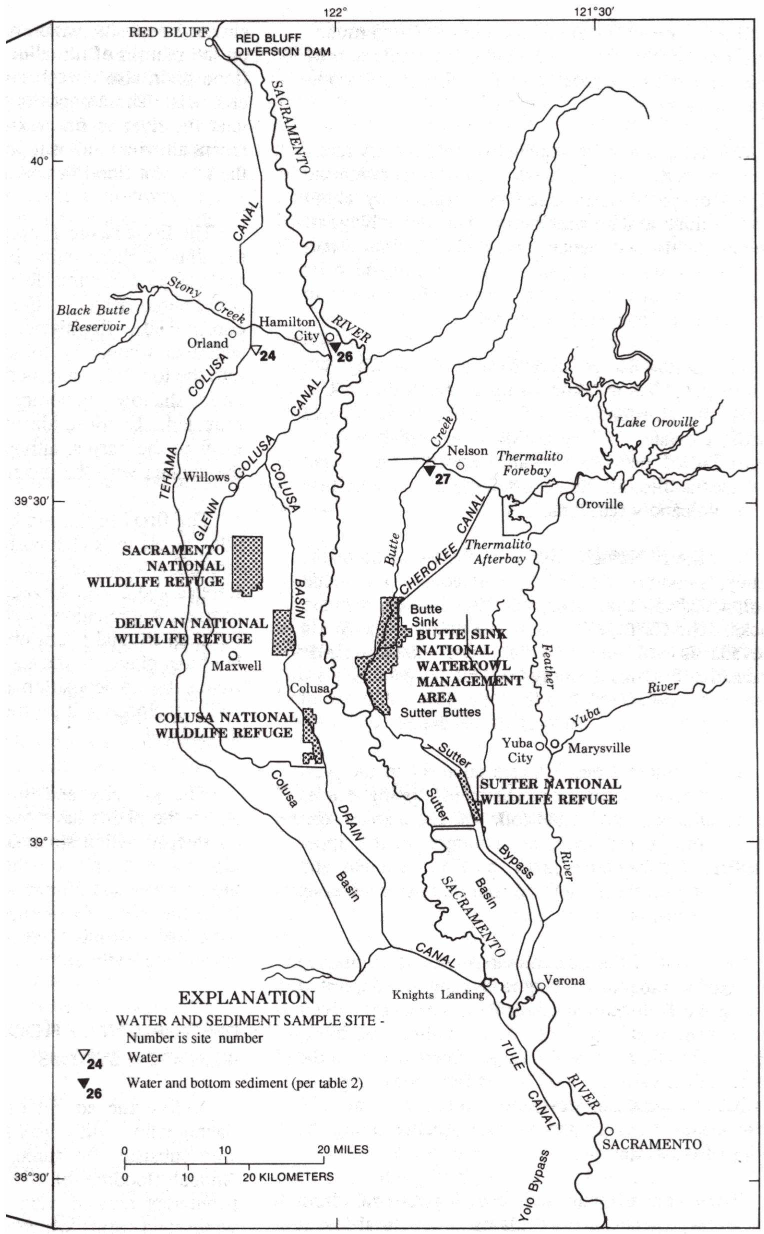
Figure 1(d)
USGS Sampling Sites
(Appendix C, Data set code e)



During both dry and wet years, much of the nitrate load in the San Joaquin River can be attributed to subsurface agricultural drainage discharged to Mud and Salt sloughs.

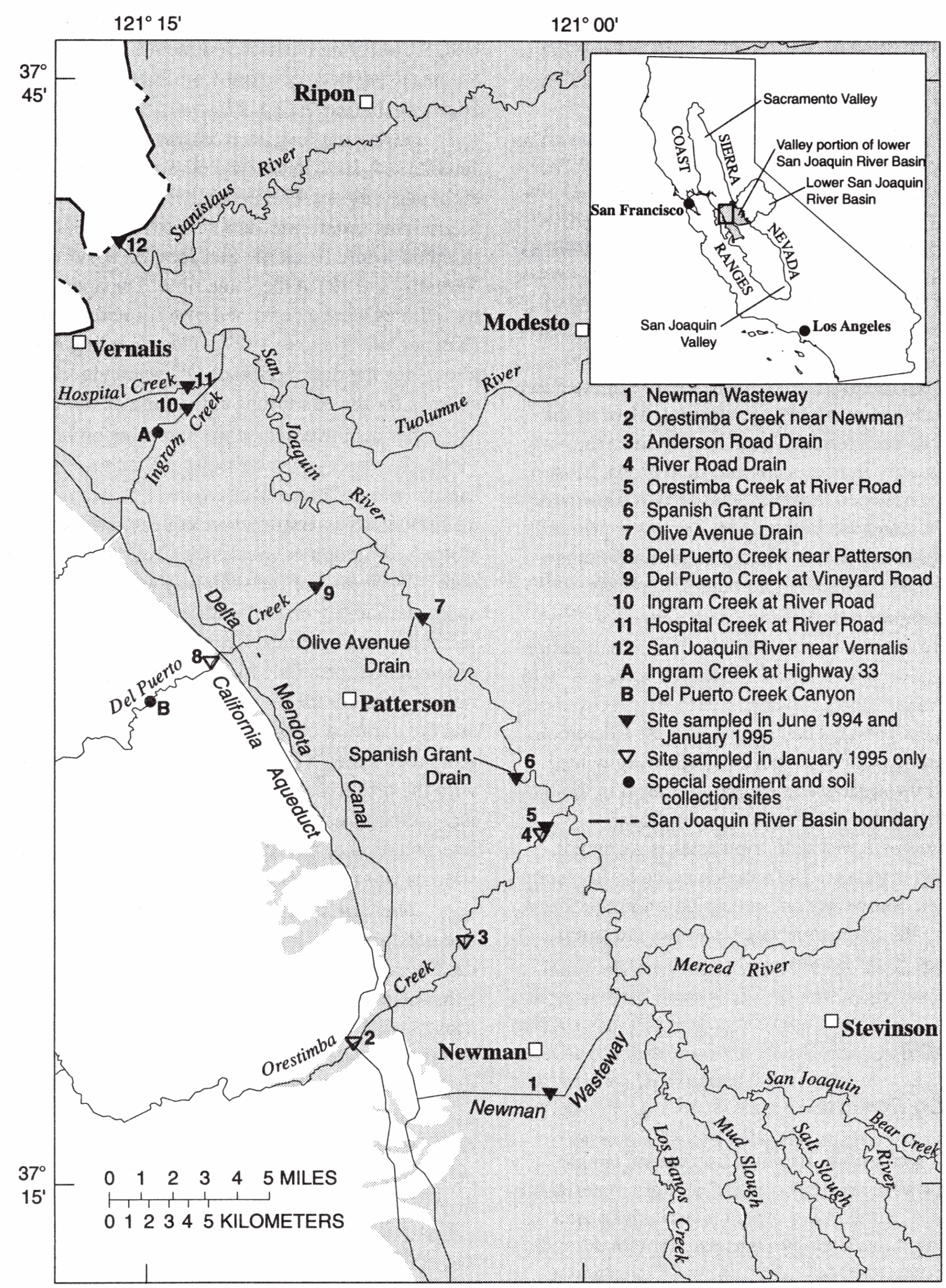
Source: Dubrovsky, *et al*. (1998)

Figure 1(e)
USGS Sampling Sites in Sacramento Valley
(Appendix C, Data set code f)



Source: Dileanis, *et al*. (1992)

Figure 1(f)
USGS Sampling Sites
(Data set from Appendix D)



Source: Kratzer (1998a)

Figure 1(g)
USGS Sampling Sites
(Appendix C, Data set code d)

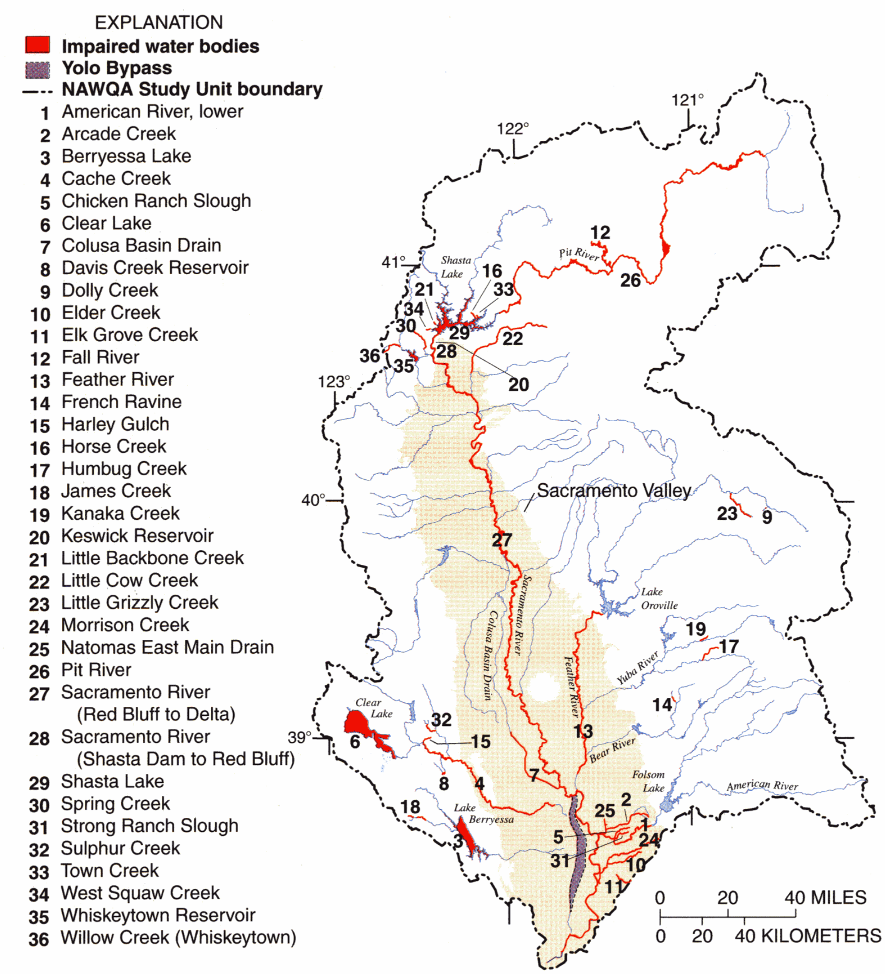
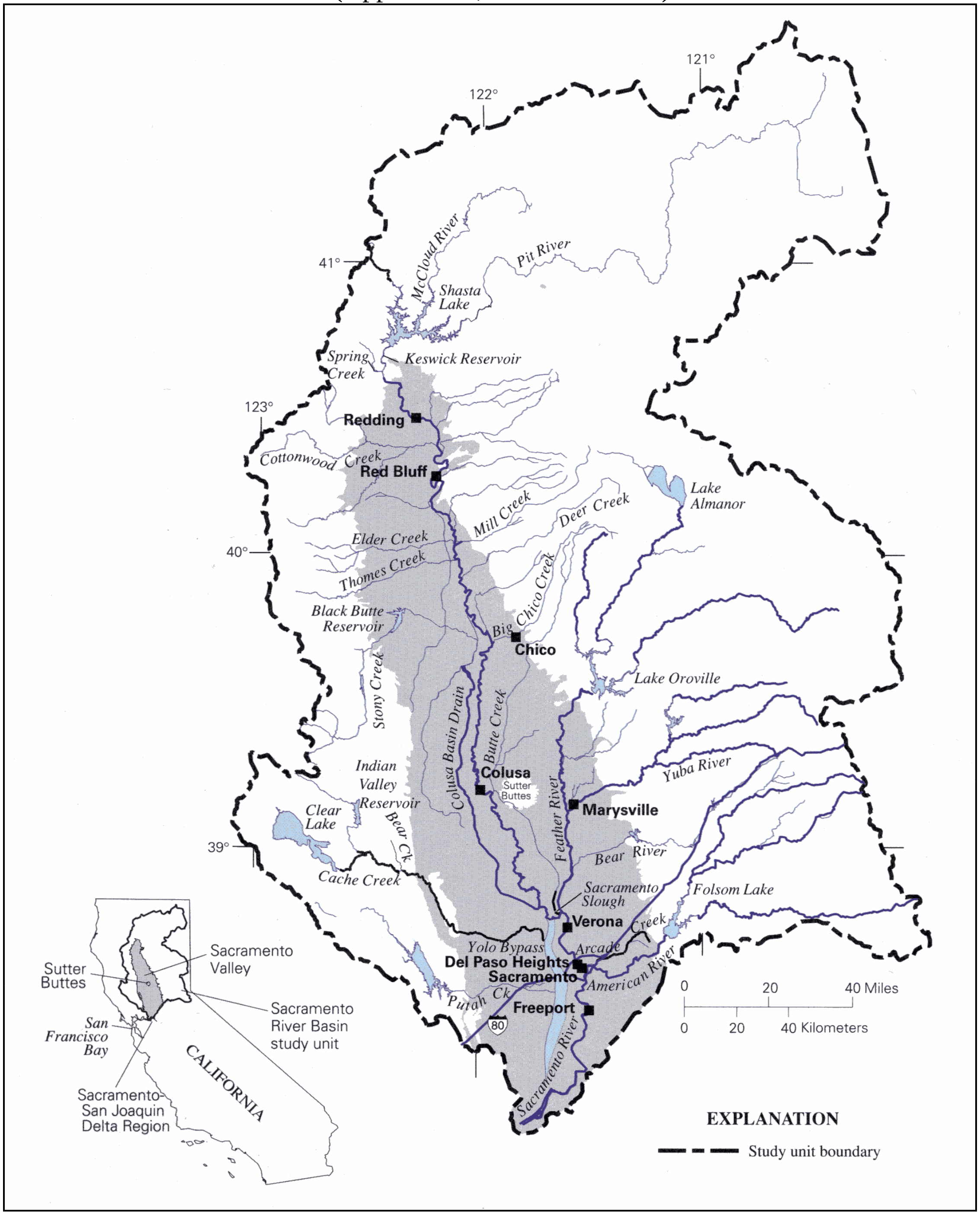


Figure 8. Impaired water bodies of the Sacramento River Basin according to the California 303(d) list (U.S. Environmental Protection Agency, accessed January 2, 2000). Impaired water bodies require the implementation of a management plan called a Total Maximum Daily Load (TMDL) to bring the water body into compliance with existing standards. Most of the impairments are the result of pesticides from agricultural or urban use, or from metals derived from historical mining operations.

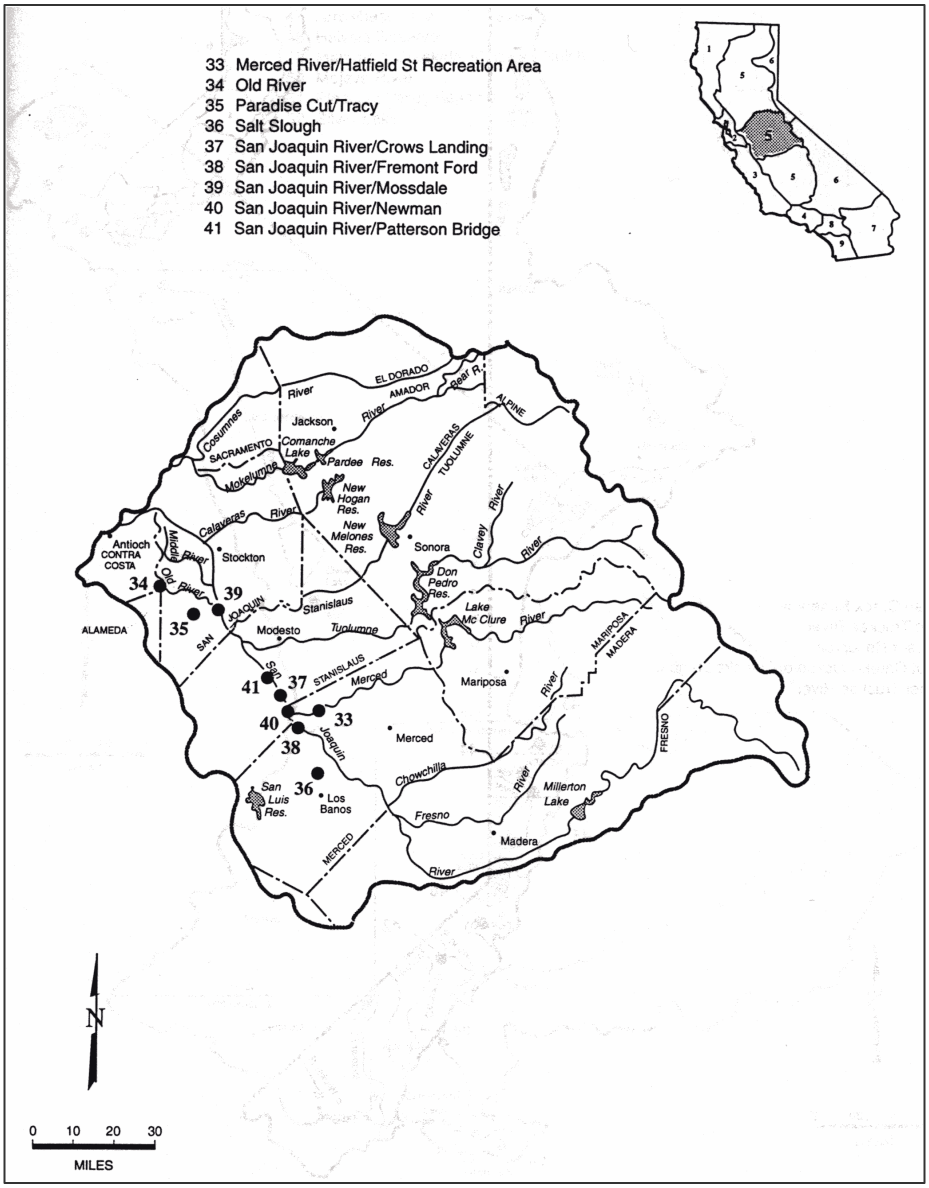
Source: Domagalski, *et al*. (2000)

Figure 1(h)
USGS Sampling Sites - Sacramento River Watershed
(Appendix C, Data set code d)



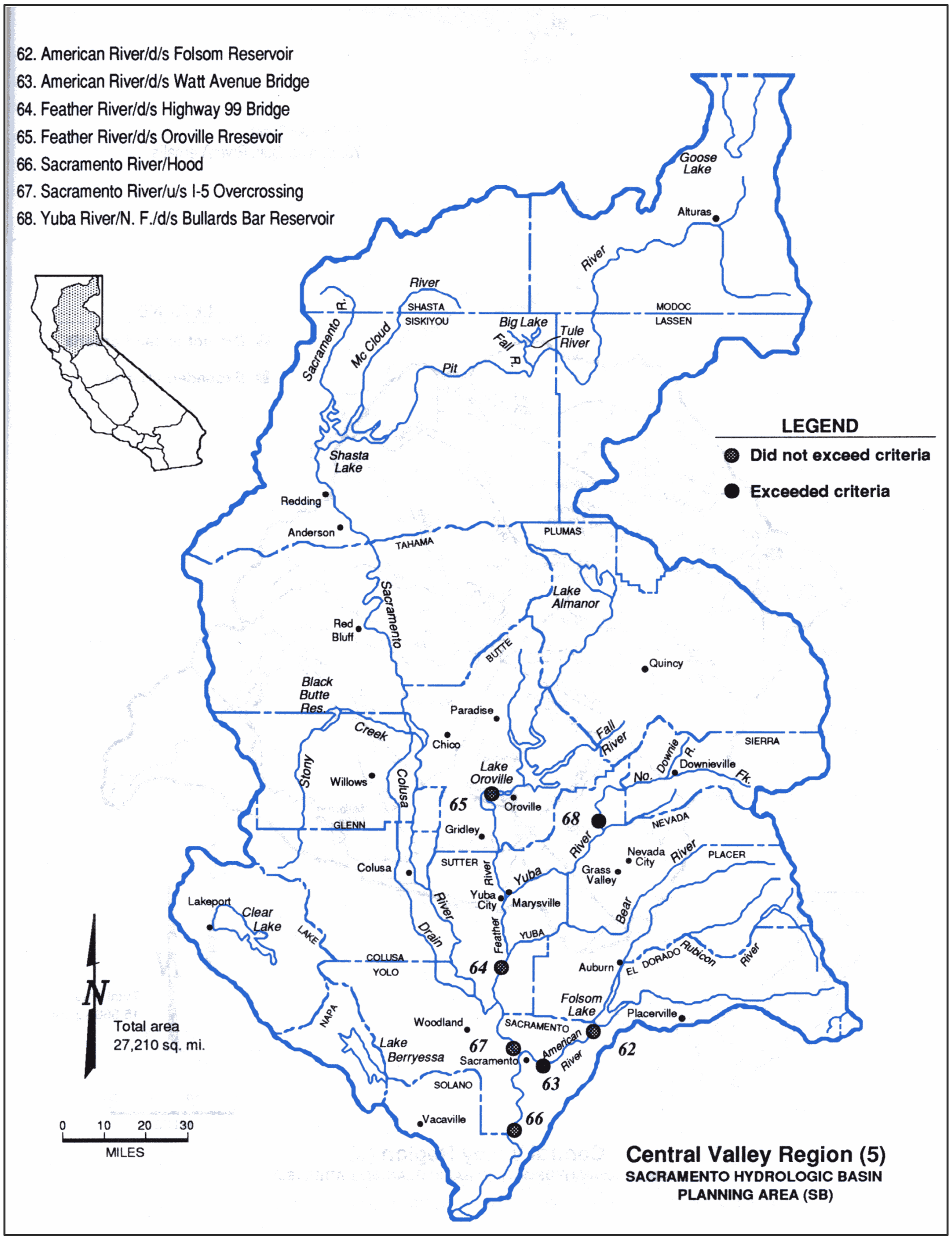
Source: Domagalski and Dileanis (2000)

Figure 1(i)
TSMP Monitoring Stations in San Joaquin Hydrologic Basin Planning Area
Central Valley Region (5) - 1994-95
(Appendix C, Data set code g)



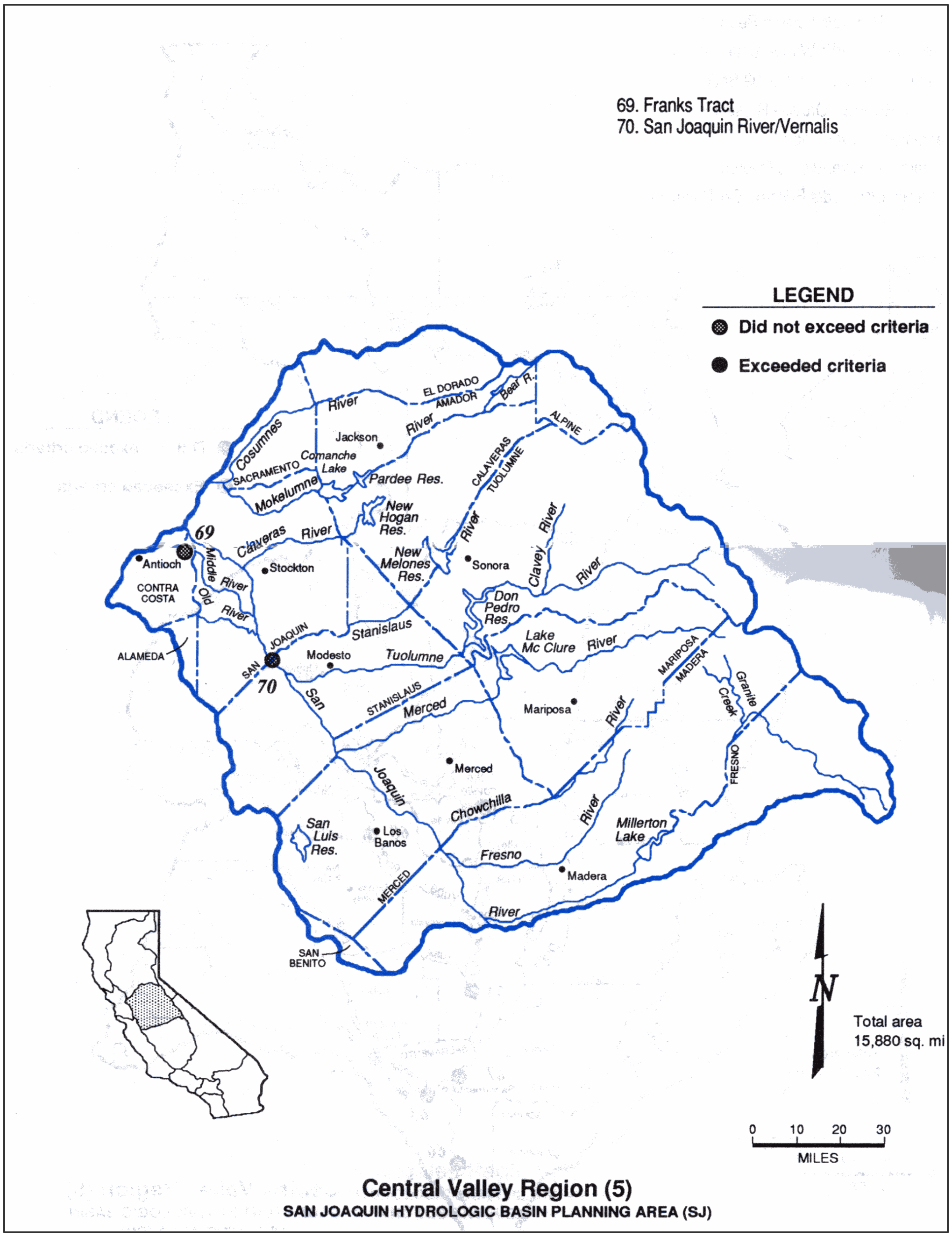
Source: Rasmussen (1997)

Figure 1(j)
TSMP Monitoring Stations in Sacramento Hydrologic Basin Planning Area
Central Valley Region (5) – 1991
(Appendix C, Data set code g)



Source: Rasmussen (1993)

Figure 1(k)
TSMP Monitoring Stations in San Joaquin Hydrologic Basin Planning Area
Central Valley Region (5) – 1991
(Appendix C, Data set code g)



Source: Rasmussen (1993)

Conceptual Model for Managing Excessive Bioaccumulation of OCls

Figure 2 presents a conceptual model of the processes that govern the excessive bioaccumulation of OCls in edible fish. Table 1 lists these processes.

Table 1
Conceptual Model of OCl Excessive Bioaccumulation Components

Central Valley Waterbody Watersheds

OCls in Former Agricultural and Urban OCl Use Areas
Runoff/Discharges in Stormwater Runoff and Tailwater Discharges
Primarily Associated with Transport of Particulates
Atmospheric Loads

Central Valley Waterbodies

OCl Uptake by Aquatic Life (Animals and Plants) from Sediments and Water
Food Web Bioaccumulation
Benthic Macro-Invertebrates → Small Animals (Fish and Other Organisms)
→ Larger Fish → Top Game Fish Predators with High Lipid Content

Impacts

Use of Fish as Food
Humans
Terrestrial Animals and Birds

Several modes of transport of the OCls from watershed sources (stormwater runoff from agricultural and urban soils, tailwater discharges from agricultural lands, wastewater discharges from municipal and industrial sources, and the atmosphere) all contribute OCls to waterbodies, where they can become incorporated into the sediments. Through bioaccumulation processes, waterbody fish acquire OCls from the sediments and/or from the benthic food chain. There is also some direct uptake by fish and other aquatic life, including algae, of dissolved OCls from the water. The food web accumulation can lead to sufficient tissue residues to be a threat to those who use the fish as food. The accumulation of OCls can also be a threat to fish-eating birds and animals.

Figure 3 is the conceptual model of a management program to control excessive bioaccumulation of OCls. It has two major components. One is to define the sediment and soil sources of OCls that are leading to excessive OCl residues in fish from certain Central Valley Waterbodies. The other is to define waterbodies with fish that have excessive OCl levels but that have not been adequately sampled thus far. Information developed from these two components should be the basis for developing the management implementation plan, wherein an allocation of the responsibility for the sources of OCls for each Waterbody with excessive OCls in fish tissue is to be defined.

Figure 2

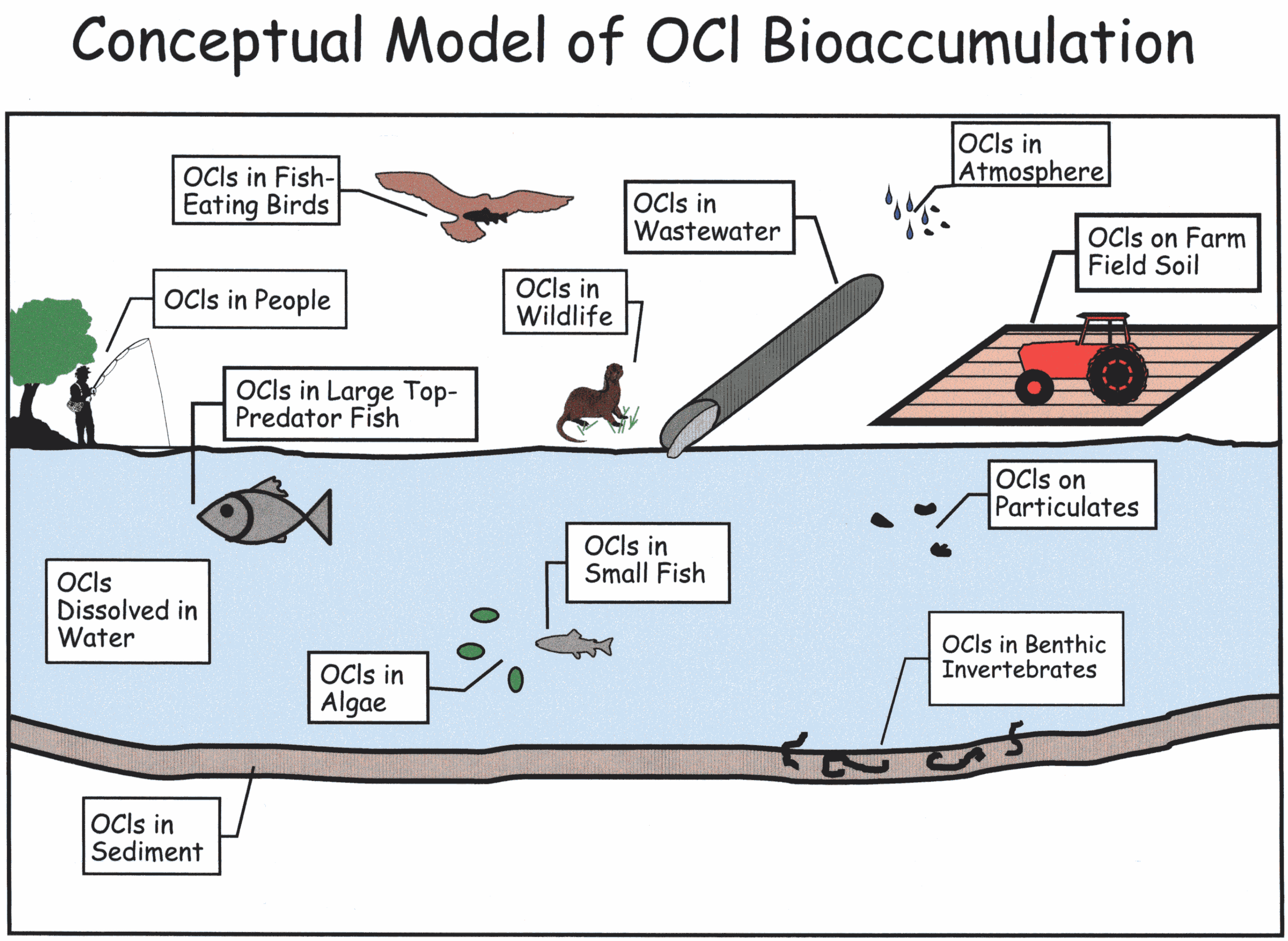
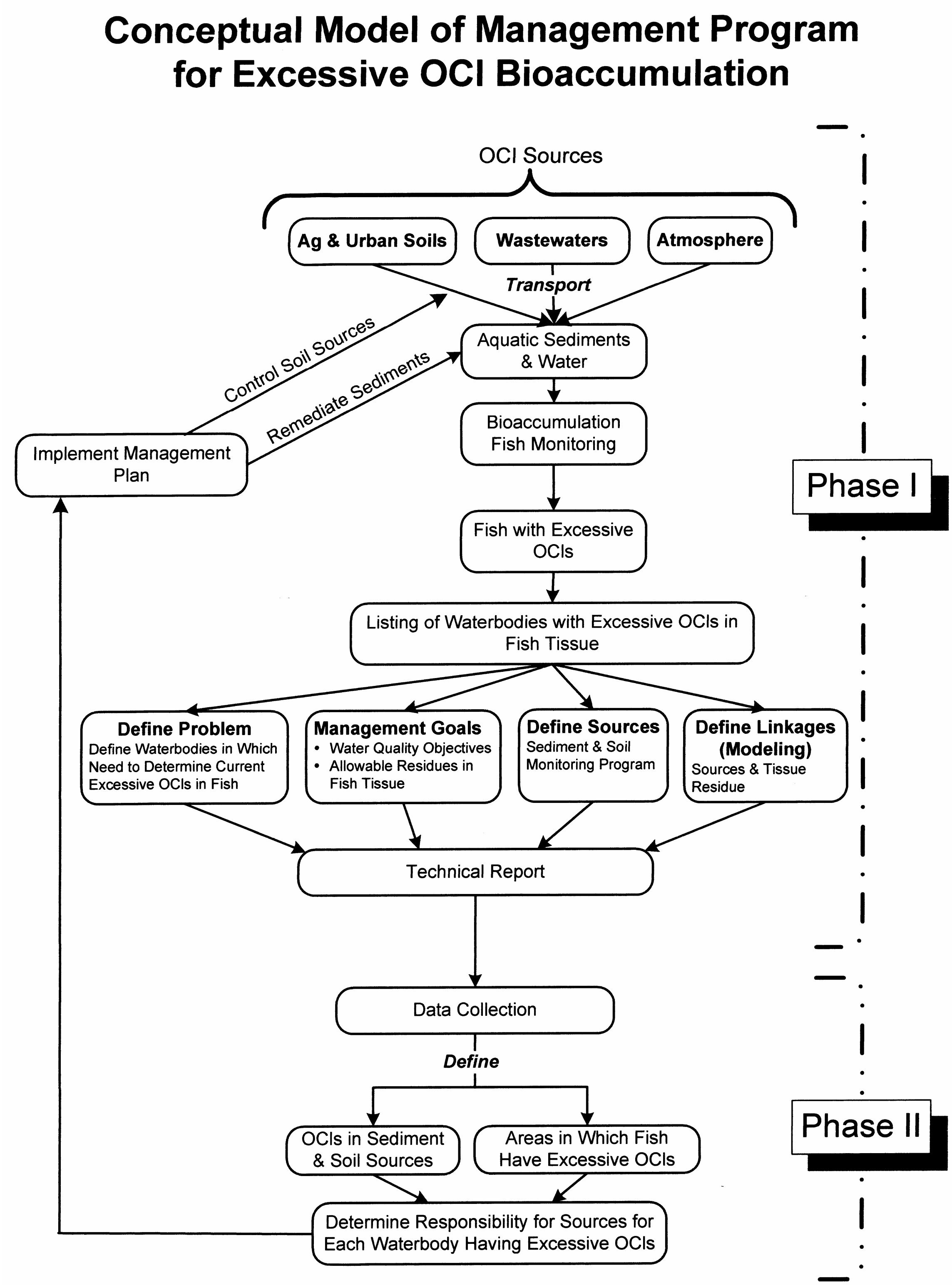

Conceptual Model of OCl Bioaccumulation
OCls in Fish-Eating Birds
OCls in People
OCls in Large Top-Predator Fish
OCls in Wildlife
OCls in Wastewater
OCls in Atmosphere
OCls on Farm Field Soil
OCls on Particulates
OCls Dissolved in Water
OCls in Small Fish
OCls in Algae
OCls in Benthic Invertebrates
OCls in Sediment

Figure 3


Conceptual Model of Management Program
for Excessive OCl Bioaccumulation
OCl Sources
Ag & Urban Soils
Wastewaters
Atmosphere
Transport
Aquatic Sediments & Water
Bioaccumulation Fish Monitoring
Fish with Excessive OCls
Listing of Waterbodies with Excessive OCls in Fish Tissue
Control Soil Sources
Remediate Sediments
Implement Management Plan
Define Problem
Define Waterbodies in Which Need to Determine Current Excessive OCls in Fish
Management Goals
• Water Quality Objectives
• Allowable Residues in Fish Tissue
Define Sources
Sediment & Soil Monitoring Program
Define Linkages (Modeling)
Sources & Tissue Residue
Technical Report
Data Collection
Define
OCls in Sediment & Soil Sources
Areas in Which Fish Have Excessive OCls
Determine Responsibility for Sources for Each Waterbody Having Excessive OCls
Phase I
Phase II

This management implementation plan then becomes the basis for the CVRWQCB Basin Plan Amendment in which, through a California Environmental Quality Act (CEQA) process, a program is developed to control the excessive OCls. This program should be directed toward control of the soil sources of OCls that are continuing to contribute OCls that are accumulating in Waterbody sediments and fish tissue. It should also focus on remediating OCl "hot spots" in sediments that have been shown to be potentially significant sources of OCls that are accumulating to excessive levels in fish.

The conceptual model shown in Figure 3 includes a phased approach, where the first phase of the management plan is devoted to collecting and analyzing the existing information base. The Waterbodies containing fish with excessive concentrations of OCls and undergoing remediation of sources and/or sediments, will then be monitored through a Phase II. This monitoring is to provide information to better define the linkage between the concentrations of OCls in water/sediments and the fish tissue residues. Because of the lack of definitive knowledge in this area, remediation will likely have to be undertaken in a number of steps (adaptive management) to eventually control excessive OCl bioaccumulation in fish tissue.

Overview of Issues

Organochlorine Pesticides. Davis, *et al*. (2000) have summarized the information available on OCl pesticide use in California. Presented below is information based on the Davis, *et al*., review. According to Davis, *et al.* (2000), limited data are available on DDT use in California. Davis, *et al.* (2000) state,

> *"Pesticide use reporting began in 1970, when DDT use was waning rapidly. DDT use in 1970 was 1,165,000 lbs, dropping to 111,000 lbs in 1971 and 81,000 lbs in 1972. From 1973 on less than 200 lbs per year were used (Mischke et al. 1985)."*

In 1984 the California Assembly directed the California Department of Food and Agriculture to investigate possible DDT sources (Mischke, *et al*., 1985). This involved a statewide survey of DDT concentrations in the soils from agricultural areas. DDT residues were found wherever DDT was used historically. All 99 samples analyzed from 32 counties contained measurable DDT. Many samples collected in the 1984 survey contained DDT concentrations above 1 mg/kg dry weight. The report concluded that residues from legal agricultural applications of DDT appeared to be the source of DDT contamination in California rivers.

In the 1960s and 1970s toxaphene was used extensively on cotton. Toxaphene use continued into the 1970s until its registration was canceled by the US EPA in 1982. Areas of the Central Valley where cotton production has occurred are areas in which there was heavy use of DDT and toxaphene.

Both chlordane and dieldrin were extensively used for structural termite control. Agricultural use of chlordane included application on corn, grapes, strawberries and other crops. Beginning in 1983 chlordane use was restricted to underground termite control. In April 1988 further sale of chlordane was prohibited.

According to Davis, *et al.* (2000),

> *"Dieldrin was used on over 40 agricultural crops and for soil treatment around various fruits, nuts and vegetables, and also in mosquito control, as a wood preservative, and in moth proofing (Harte et al. 1991, U.S. EPA 1995a). All uses on food products were suspended in 1974. All uses except subsurface termite control, dipping of nonfood roots and tops, and moth proofing in a closed system were banned in 1985. These remaining uses were voluntarily canceled by industry."*

Each of the listed Waterbodies' watersheds contain agricultural and, in some instances, urban areas where organochlorine (Group A) pesticides and/or DDT have been used. Some of these pesticides were widely and intensively used on a variety of crops throughout the Central Valley. Further, a number of the pesticides, such as DDT, chlordane, and dieldrin, have been used in urban areas for pest control. This has resulted in residues of these pesticides accumulating in the surface soils throughout the Central Valley.

While the use of the Group A pesticides and DDT in agricultural and urban areas has been banned for at least one, and, for many of the OCl pesticides, several, decades, USGS monitoring of surface waters in the Central Valley conducted in the early to mid-1990s found concentrations of some of the Group A pesticides and DDT that potentially could bioaccumulate to excessive levels in a waterbody's fish. While there have been no studies that have systematically evaluated current sources of the OCls that are bioaccumulating to excessive levels in the listed Waterbodies, it is expected that current stormwater runoff from agricultural, urban, and other areas in many of the listed Waterbodies' watersheds could contain potentially significant concentrations of the OCl(s) that have bioaccumulated to a sufficient extent to lead to the listing. Further, it is also expected that current domestic and some industrial wastewater discharges could contain one or more OCls that could contribute to current excessive bioaccumulation of OCls in some fish receiving these discharges.

In addition to stormwater transport of these pesticides from the point of application to downstream waterbodies, there has been atmospheric transport from the point of application, which contributes to OCl residues in a waterbody's fish and sediments. It is believed, although not quantified, that current atmospheric transport of the OCls is not a significant pathway that leads to sufficient concentrations of bioavailable OCls in the listed Waterbodies to significantly contribute to the excessive fish tissue residues.

A number of studies conducted in other areas have shown that aquatic sediments are a significant "sink" (reservoir source) for OCls that can bioaccumulate in some fish. Further, it is known that the total concentrations of an OCl in sediments are not a reliable indicator of the bioavailable fraction of the sediment-associated OCl that can lead to excessive bioaccumulation in edible fish. There is essentially no information on the current OCl concentrations and their bioavailability in the listed Waterbodies' sediments.

The 303(d) listing of the Waterbodies that took place in 1998 was based in part upon approaches for determination of excessive bioaccumulation of some of the OCls in edible fish tissue that are not accepted as reliable for assessing excessive concentrations that are a threat to human health in edible fish tissue. According to Bruns (pers. comm., 2002), some of the 1998 303(d) listing involved use of an approach that was not based on human health risk, such as the FDA tolerance levels and the so-called (in California) "NAS" guidelines. Further, some of the information that was used for the 1998 303(d) listing was limited in scope in terms of number of fish recently analyzed and waterbodies examined.

The Central Valley Regional Water Quality Control Board (CVRWQCB 2002) staff has proposed two changes in the updated 303(d) list for Central Valley waterbodies with respect to the OCl listings. They are proposing to add Orestimba Creek to this list, based on the finding that DDE has been found in Creek waters above drinking water MCLs. They are also proposing to de-list the Lower American River for Group A pesticides, based on *"... new data showing that the NAS and US FDA criteria are not now being exceeded. Therefore the WQO for the Group A pesticides for toxicity of pesticides are being attained and no longer need to be listed on the 303(d) list for Group A pesticides."*

There is need to determine, for each of the listed Waterbodies, as well as other Central Valley waterbodies, the current concentration of OCl residues in edible fish tissue. These residues should be compared to OEHHA screening values which have been adjusted for local fish consumption rates. This information is essential to defining the waterbodies within the Central Valley where OCls have bioaccumulated to excessive levels in edible fish.

Polychlorinated Biphenyls (PCBs). PCBs have been found at excessive concentrations in Central Valley fish at several locations, such as in fish taken from the San Joaquin River at Vernalis, from Smith Canal in the city of Stockton, and from the Sacramento River near Sacramento. There are no specifically identified sources of PCBs for the locations where they have been found in fish tissue. The situation with respect to PCBs that are accumulating to excessive levels in a Waterbody's fish, while analogous in some respects, is different than the OCl pesticide situation with respect to past sources. PCBs were widely used as electrical transformer heat exchange fluids. Their primary property of interest is that they do not burn and that they do not significantly degrade in electrical transformers and capacitors. PCBs gain entrance to the environment through leaks or spills from transformers or from the manufacture of capacitors that contain PCBs, where they were discharged in the wastewaters from the manufacturing facility. The classic example of this situation is the General Electric capacitor plant on the Upper Hudson River in New York State, which discharged sufficient PCBs to cause striped bass throughout the Hudson River into New York Harbor to contain excessive concentrations in their edible tissue.

PCBs were also widely used in a variety of industrial processes, which resulted in their being present in wastewater discharges from the processing facility. PCBs, like the organochlorine legacy pesticides, were banned from further use 20 or so years ago. They are, however, highly persistent in the environment, and they tend to bioaccumulate through the food web in edible fish tissue. Generally, the sources of PCBs for Central Valley Waterbodies that have been listed as having excessive PCBs in edible fish are more restricted than the OCl pesticides. However, it is often difficult to predict the specific source(s) of PCBs for a waterbody that has bioaccumulated excessive concentrations in edible fish.

An example of this situation occurs in Smith Canal, within the city of Stockton. In 1978, studies funded by the DeltaKeeper and the Central Valley Regional Water Quality Control Board (Davis, *et al.*, 2000) found that certain fish (largemouth bass and white catfish) taken from Smith Canal contained excessive PCBs. A recently completed study by Lee, *et al.* (2002) showed that the sediments in part of Smith Canal contained greatly elevated concentrations of PCBs. Smith Canal's primary water inputs are stormwater runoff from Stockton and tidal water from the Deep Water Ship Channel. Based on the data developed by Lee, *et al.* (2002), the source of PCBs found in Smith Canal sediments is stormwater runoff, possibly from a former industrial area within the City.

Dioxins/Furans. Dioxins and furans are a group of related organic chemicals that contain chlorine. Dioxins are formed in low-temperature combustion, such as in forest fires or burning of wood and wastes. Studies in the San Francisco Bay region (SFBRWQCB, 1997) and elsewhere (Fisher, *et al.*, 1999) show that dioxins have been found in stormwater runoff from highways, indicating that they may be present in automobile exhaust. Further, they are present in some industrial wastewater discharges. They were a contaminant in the manufacture of 2,4,5-T, a herbicide, which was widely used for a variety of purposes, including as the defoliant "Agent Orange" in Vietnam.

Previously, dioxins and furans were discharged to the Sacramento River in significant amounts by the Simpson Paper Company, located at Anderson, California. Dioxins and furans were formed in the chlorine bleaching of wood pulp. In the early 1990s, fish taken from the Sacramento River contained sufficient dioxins/furans to be a threat to cause cancer in those who used the fish as food. Simpson Paper Company changed its paper manufacturing process, which eliminated the production of dioxins/furans. By the mid-1990s, the concentrations of dioxins and furans in the fish taken from the mainstem of the Sacramento River decreased to acceptable levels. However, dioxins and furans are highly persistent in aquatic sediments and are likely present in the Delta sediments, as a result of scour of Sacramento River-derived sediment residues of dioxins and furans.

Another source of dioxins/furans for the Delta is the McCormick & Baxter Superfund site (US EPA, 2002a). (Also, consult DHS, 1997a,b.). The site was a creosoting company, where, as a byproduct, dioxins/furans were released. McCormick & Baxter Creosoting Company is a 29-acre former wood-preserving facility located in an industrial area near the Port of Stockton. Old Mormon Slough, which is connected to the Stockton Deep Water Channel, borders the site on the north. From 1942 to 1990, McCormick & Baxter treated utility poles and railroad ties with creosote, pentachlorophenol (PCP), and compounds of arsenic, chromium and copper. This operation has contaminated the site and underlying groundwaters with PCP. Sediments of Old Mormon Slough adjacent to the site are also contaminated, primarily with PAHs and dioxins. Site-related contaminants have also been detected in fish caught in the vicinity of the site (US EPA, 2002a).

According to J. Bruns (pers. comm., 2002), there may also have been a source of dioxins in the western Delta, near Antioch. No additional information on this matter is available.

Excessive bioaccumulation of dioxins and furans has been found in some fish in the Delta and in San Francisco Bay (SFBRWQCB, 1997). While there has been some detection of dioxins and furans in Central Valley waterbody fish, inadequate attention has been given to the excessive bioaccumulation of dioxins and furans in the Sacramento-San Joaquin River Delta and its tributaries. These chemicals are being found in urban area street and highway stormwater runoff (Fisher, *et al*., 1999), and therefore would be expected to be present in water and sediments near urban areas such as Sacramento and Stockton. It is unclear at this time whether the former use of 2,4,5-T as a herbicide along roadways and elsewhere in the Central Valley is a current source of dioxins and furans.

There is need for comprehensive studies to determine the extent of edible fish tissue contamination by dioxins and furans within Central Valley waterbodies and, where excessive concentrations are found in edible fish tissue, to determine likely sources of the dioxins and furans that are bioaccumulating to excessive levels.

Overall. Overall, while previous studies have been adequate to determine that there is an OCl excessive bioaccumulation problem in some of the Central Valley Waterbody fish, the current degree of contamination and the current sources of the OCls are poorly understood.

Regulatory Issues

The CVRWQCB (1998) Basin Plan presents the regulatory approach used by the CVRWQCB to control water pollution in the Central Valley. The foundation of this control program is the establishment of beneficial uses for each of the Central Valley waterbodies and water quality objectives to protect these uses.

Beneficial Uses. Each of the listed Waterbodies, either directly or through the Tributary Rule, has as a designated beneficial use of "freshwater aquatic life habitat." As such, they are expected to be suitable areas for fish development, where the fish taken from these Waterbodies should be free of chemicals that are a threat to the health of those who use the fish as food. Further, the beneficial use "commercial and sport fishing (COMM)," is defined by the CVRWQCB (1998) Basin Plan as,

> *"Uses of water for commercial or recreational collection of fish, shellfish, or other organisms including, but not limited to, uses involving organisms intended for human consumption or bait purposes."*

While the waterbodies within the Central Valley have not been designated as COMM by the CVRWQCB, sportfishing, where the fish are used as food, is an important beneficial use of many of the Central Valley waterbodies, including the listed Waterbodies.

Water Quality Objectives. The CVRWQCB (1998) Basin Plan states,

> *"All waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life. This objective applies regardless of whether the toxicity is caused by a single substance or the interactive effect of multiple substances. Compliance with this objective will be determined by analyses of indicator organisms, species diversity, population density, growth anomalies, and biotoxicity tests of appropriate duration or other methods as specified by the Regional Water Board.*
>
> *The Regional Water Board will also consider all material and relevant information submitted by the discharger and other interested parties and numerical criteria and guidelines for toxic substances developed by the State Water Board, the California Office of Environmental Health Hazard Assessment, the California Department of Health Services, the U.S. Food and Drug Administration, the National Academy of Sciences, the U.S. Environmental Protection Agency, and other appropriate organizations to evaluate compliance with this objective."*

Pesticides. The *Water Quality Objectives* section of the Basin Plan includes the following potentially applicable statements regarding pesticides in the subsection entitled *Water Quality Objectives for Inland Surface Waters:*

- *"No individual pesticide or combination of pesticides shall be present in concentrations that adversely affect beneficial uses*
- *Discharges shall not result in pesticide concentrations in bottom sediments or aquatic life that adversely affect beneficial uses*
- *Pesticide concentrations shall not exceed those allowable by applicable antidegradation policies*
- *Pesticide concentrations shall not exceed the lowest levels technically and economically achievable.*

> *For purposes of these objectives, the term pesticide shall include: (1) any substance, or mixture of substances, which is intended to be used for defoliating*

plants, regulating plant growth, or for preventing, destroying, repelling, or mitigating any pest, which may infest or be detrimental to vegetation, humans, animals, households, or be present in any agricultural or nonagricultural environment whatsoever, or (2) any spray adjuvant, or (3) any breakdown products of these materials that threaten beneficial uses. Note that discharges of 'inert' ingredients included in pesticide formulations must comply with all applicable water quality objectives."

CTR Criteria. The US EPA (2000a) Region 9 promulgated the California Toxics Rule (CTR). The CTR provides the toxic chemical water quality criteria that are incorporated into the Regional Board's Basin Plan objectives. Therefore, these criteria/objectives are appropriate regulatory goals for an OCl management plan. Table 2 presents the California Toxics Rule water quality criteria for the OCl chemicals of concern in this guidance. These criteria/objectives provide information on the one-hour average (acute) and four-day average (chronic) concentrations of these chemicals that would not be expected to be adverse to aquatic life. The US EPA (2000a) has indicated that several of the OCl criteria are based on 1980 reports developed by the Agency. Additional data on the toxicity of OCl pesticides to various forms of aquatic life is available from the US EPA (2002b) Ecotoxicity Database. This database contains information on the toxicity of various pesticides to various forms of aquatic life under various exposure conditions.

Table 2
Freshwater Column Target Values for Organochlorine Compounds

Constituent	**Freshwater**		**Human Health (10^{-6} risk for carcinogens) For consumption of:**	
	CMC (acute) (µg/L)	**CCC (chronic) (µg/L)**	**Water & Organisms (µg/L)**	**Organisms Only (µg/L)**
Aldrin	3	--	0.00013	0.00014
Chlordane	2.4	0.0043	0.00057	0.00059
DDT*	1.1	0.001	0.00059	0.00059
Dieldrin	0.24	0.056	0.00014	0.00014
Endosulfan	0.22	0.056	110	240
Endrin	0.086	0.036	0.76	0.81
Heptachlor	0.52	0.0038	0.00021	0.00021
Heptachlor Epoxide	0.52	0.0038	0.00010	0.00011
Hexachlorocyclohexane (including lindane), gamma-BHC	0.95	--	0.019	0.063
PCBs	--	0.014	0.00017	0.00017
Toxaphene	0.73	0.0002	0.00073	0.00075
Dioxins/Furans	--	--	0.000000013	0.000000014

Source: US EPA (2000a)
-- no value provided
Criteria are based on carcinogenicity of 10^{-6} risk.
* DDT value cited for 4,4' DDT, but value will apply to one isomer or sum of all isomers detected.

While the criteria for the OCl chemicals in Table 2 are for total water column concentrations, there is considerable evidence that particulate forms of these chemicals in the water column are nontoxic to aquatic life. The US EPA (1995b, 2000a), in developing the CTR criteria, recognized that some of the potentially toxic chemicals, such as the particulate forms of certain heavy metals, are nontoxic, and regulate these heavy metals as the dissolved form with respect to their potential to cause toxicity to aquatic life. A similar situation should occur for the OCl water quality criteria. However, until the Agency makes the change from total OCls to dissolved forms of OCls, for current regulatory purposes, such as a management goal, the total water column concentration of the OCls is used to determine compliance with a Basin Plan objective.

Also presented in Table 2 are the concentrations of the chemicals of concern that can, under worst-case conditions, bioaccumulate in aquatic life to excessive levels. As indicated, there are often several orders of magnitude lower concentrations of concern for bioaccumulation than for aquatic life toxicity. This arises from the food web bioaccumulation of these chemicals from water to higher-trophic-level organisms. The "worst case" characterization is based on the OCl being present in the water column in 100 percent bioavailable form for a sufficient period of time to allow bioaccumulation.

It has been understood since the early 1970s that the worst-case bioaccumulation numeric concentrations apply to a limited number of waterbodies where there is little or no binding of the chemical of concern by particulates in the water column. Under conditions where there is suspended sediment present in the aquatic system of concern, the sediment and the organisms compete for the chemical, thereby allowing a much higher concentration of the chemical in water without achieving critical tissue residues. The fact that the worst-case-based water quality criteria, such as those listed in Table 2, are not reliable predictors of the bioaccumulation that will occur in many waterbodies is causing the US EPA to shift its regulatory approach from the worst-case water column approach to a site-specific biota sediment accumulation factor (US EPA, 2000b), where the critical water column concentration of a chemical (such as the legacy pesticides, PCBs or dioxins) is determined based on the concentration that is expected to cause excessive bioaccumulation in organism tissue. This is not a new concept. The authors, as part of their work with the American Fisheries Society Water Quality Committee in the late 1970s, together with the other committee members who were on the PCB review committee, concluded (Veith, *et al.*, 1979) that this is the approach that should be used, where a site-specific bioaccumulation factor should be used rather than a worst-case-based water quality criterion to judge excessive water concentrations of PCBs.

The CTR criteria are CVRWQCB Basin Plan objectives for regulating OCls in the water column. These criteria should be used with caution because of the worst-case nature of the assumptions that were used in developing the criteria with respect to both aquatic life toxicity and excessive bioaccumulation. Using these criteria/objectives based on total concentrations of OCls in the water column, especially in turbid waters, will tend to significantly overestimate the potential aquatic life toxicity and the potential to bioaccumulate to excessive levels in edible fish tissue.

The US EPA is beginning to address the more appropriate regulation of bioaccumulatable chemicals, such as the OCls, based on tissue residues rather than water column concentrations. Pendergast (pers. comm., 2000) who heads the US EPA's Office of Water TMDL Program, has indicated that it is the Agency's intent to regulate bioaccumulatable chemicals based on tissue residues rather than water column concentrations, such as those listed in Table 2. The US EPA (2001a,b), as part of developing a more reliable approach for regulating mercury, is adopting a tissue residue approach rather than a worst-case water column approach. Wood (pers. comm., 2002), who heads the US EPA Region 9 water quality criteria program, has indicated that the US EPA will likely eventually adopt a similar approach to that being adopted for mercury for regulating bioaccumulation of OCls.

There is an important aspect of the magnitude of the water quality criteria concentrations listed in Table 2 for aquatic life toxicity and, especially, for those that are based on worst-case bioaccumulation conditions, in that these concentrations are typically lower than the detection limits of the frequently used analytical methods for measuring water column concentrations of these chemicals. The authors have repeatedly encountered situations where those not familiar with this situation will claim that, since the concentration of DDT, toxaphene or PCBs, etc., is less than the detection limit for the analytical method used, these chemicals would not cause water quality problems. In fact, concentrations that are sometimes orders of magnitude less than what can be readily measured by analytical methods frequently used, can bioaccumulate to excessive levels in certain fish. The inadequate analytical method detection limit situation provides additional justification for regulating bioaccumulatable chemicals (such as the OCls) based on critical tissue residues, rather than water column concentrations.

The critical concentrations of these chemicals in fish tissue for protection of human health are, in general, easily measured with readily available analytical methods. Further, although attempting to measure many of these chemicals in sediments is often fraught with significant interferences by other chemicals that are measured like these chemicals but are not of water quality concern, the bioaccumulated residues in animal tissue are "cleaned up" through the bioaccumulation process so that they are, in general, easily measured.

Drinking Water MCLs. In addition to being concerned about the concentrations of OCls in water that are potentially adverse to aquatic life through toxicity and to humans through excessive bioaccumulation in fish and other aquatic life as listed in the CTR criteria (Table 2), there is also concern about the concentrations of the OCls that could be adverse to the use of a water for domestic water supply purposes. The finding of an OCl above a US EPA maximum contaminant level (MCL) would constitute a violation of the CVRWQCB Basin Plan. As discussed in a subsequent section, in reviewing existing data, this situation has occurred in the 1990s in the San Joaquin River watershed. Table 3 presents the US EPA and OEHHA drinking water MCLs, as well as the OEHHA public health goals for the OCls of concern in this report.

The US EPA has not established a drinking water MCL for DDT, DDD, and DDE. These constituents are regulated in the CTR criteria. The OEHHA public health goals reflect the Agency's concern that any concentration above the goal is adverse to those who consume the water over extended periods of time. A comparison of Tables 2 and 3 shows that the critical concentrations for the OCls that affect aquatic life are, in general, somewhat lower than the concentrations allowed in drinking water. Further, the critical concentrations of the OCls that can bioaccumulate under worst-case conditions to excessive levels in fish tissue are often considerably lower than the drinking water MCL.

OEHHA Fish Tissue Criteria. Table 4 presents the US EPA and OEHHA fish tissue screening values for evaluation of excessive bioaccumulation of selected chemicals. These are the same values listed by the US EPA (2002c) Region 9 as fish tissue TMDL target values for organochlorine compounds in Upper Newport Bay and its tributaries.

Table 3
Drinking Water MCLs

CHEMICAL	US EPA Drinking Water MCL (µg/L)	OEHHA Drinking Water MCL (µg/L)	OEHHA Public Health Goal (µg/L)
Chlordane	2	0.1	0.03
Total DDT	see CTR criteria		
Dieldrin	7		
Endrin	2	2	1.8
Heptachlor	0.4	0.01	0.008
Heptachlor epoxide	0.2	0.01	0.006
?-hexachlorocyclohexane (lindane)	0.2	0.2	0.032
Toxaphene	3	3	
PCBs	0.5	0.5	
Dioxin (2,3,7,8-TCDD)	3×10^{-5}	3×10^{-5}	

Source: www.epa.gov/safewater/mcl.html, US EPA (2002d)
Source: www.oehha.ca.gov/water, OEHHA (2002)

Table 4
US EPA and OEHHA Fish Tissue Screening Values

CHEMICAL	US EPA Value[1] (µg/kg wet weight)	OEHHA Value[2] (µg/kg wet weight)
Chlordane[3]	80	30
Total DDT[4]	300	100
Dieldrin	7	2
Total endosulfan[5]	60,000	20,000
Endrin	3000	1000
Heptachlor epoxide	10	4
?-hexachlorocyclohexane (lindane)	80	30
Toxaphene	100	30
PCBs[6]	10	20
Dioxin TEQ[7]	0.7 ppt	0.3 ppt

Source: SARWQCB (2000)

1: USEPA SVs (US EPA, 1995a) for carcinogens were calculated for a 70 kg adult using a cancer risk of 1x10-5. SVs for non-cancer effects were calculated for a 70 kg adult and exposure at the RfD (hazard quotient of 1). A fish consumption value of 6.5 g/day was used in both cases.
2: California OEHHA (1999) SVs (CLS-SVs) specifically for this study were calculated according to US EPA guidance (US EPA, 1995a). CLS-SVs for carcinogens were calculated for a 70 kg adult using a cancer risk of 1x10-5. CLS-SVs for non-cancer effects were calculated for a 70 kg adult and exposure at the RfD (hazard quotient of 1). A fish consumption value of 21 g/day was used in both cases
3: Sum of alpha and gamma chlordane, cis- and trans-nonachlor and oxychlordane.
4: Sum of othro and para DDTs, DDDs and DDEs.
5: Sum of endosulfan I and II.
6: Expressed as the sum of Aroclor 1248, 1254 and 1260.
7: Expressed as the sum of TEQs for dibenzodioxin and dibenzofuran compounds which have an adopted TEF.

The values listed in Table 4 are based on an upper-bound estimated cancer risk of one additional cancer in a population of 100,000 people who consume, on the average, 6.5 g/day (about 1 meal/month) of the fish containing the screening value concentration over their lifetime. Additional information on critical concentrations of OCls in fish tissue is provided by Brodberg and Pollock (1999) and US EPA (1997a).

The screening values listed in Table 4, when adjusted for appropriate consumption rates for people who use fish from the 11 listed Waterbodies as a regular part of their diet, are the recommended screening values that should be used as management goals in an OCl bioaccumulation management plan for a cancer risk of 10^{-5}. These are the values that have been used in this study in evaluating the existing OCl database for the Central Valley Waterbodies.

As discussed by SARWQCB (2000), the US EPA's draft guidance document for managing excessive bioaccumulation provides a tool to develop monthly consumption screening values and/or regulatory values for fish and shellfish tissue. The same approach was used by OEHHA (1999) in their development of their screening values for consumption of fish containing OCls. SARWQCB (2000) has provided information on how the magnitude of the screening value changes as a function of fish meal size and frequency of consumption. This material is discussed in a subsequent section. The technically valid approach for regulating excessive OCl bioaccumulation should be based on OEHHA screening values that are adjusted for local fish consumption rates and the appropriate cancer risk level.

FDA Action Levels. The US Food and Drug Administration (FDA) (1984) has developed Action Levels for the consumption of freshwater and marine fish that may contain hazardous chemicals. These values are presented in Table 5.

The FDA Action Levels were, at one time, widely used to judge excessive fish tissue concentrations for many of the OCls. However, as additional information became available on the specific human health threat that was associated with consumption of fish with elevated OCl residues, it became apparent that the FDA Action Levels were not protective of human health. The FDA Action Levels consider economic and other non-health-related issues in their development. As a result of this situation, the US EPA and

OEHHA developed risk-based values (presented in Table 4) for consumption of fish containing OCls.

Table 5
FDA Regulatory Action Levels (Regulatory Values) for Toxic Chemicals in Fish (wet weight)

Chemical	FDA[a] Action Levels for Freshwater and Marine Fish (Edible Portion) (µg/g) (ppm)
DDT (total)	5.0
PCB (total)	2.0[b]
Aldrin	0.3
Dieldrin	0.3
Endrin	0.3
Heptachlor	0.3
Heptachlor Epoxide	0.3
Chlordane	0.3
Lindane	--
HCH	--
Endosulfan	--
Toxaphene	5

Source: SARWQCB (2000)
-- no values provided
[a] US Food and Drug Administration. (1984). Shellfish Sanitation Interpretation: Action Levels for Chemicals and Poisonous Substances, June 21, 1984. US FDA, Shellfish Sanitation Branch, Washington D.C.
[b] A tolerance, rather than an action level, has been established for PCBs (21CFR 109, May 29, 1984). An action level is revoked when a regulation establishes a tolerance for the same substance and use.

NAS Criteria. The SWRCB staff, as part of the Toxic Substances Monitoring Program (TSMP), has been using what they call "NAS" criteria for evaluating excessive fish tissue concentrations. These values are numeric concentrations that were suggested by the National Academy of Science (NAS) and the National Academy of Engineering (NAE) in their 1972 Blue Book of water quality criteria (NAS/NAE, 1973). These values are presented in Table 6.

The NAS/NAE (1973), as part of discussing the development of these values, stated:

> *"Present knowledge is not yet sufficient to predict or estimate safe concentrations of these compounds in aquatic systems. However, residue concentrations in aquatic organisms provide a measure of environmental contamination. Therefore, specific maximum tissue concentrations have been recommended as a guideline for water quality control.*
>
> *For the protection of predators, the following values are suggested for residues in whole fish (wet weight): DDT (including DDD and DDE) – 1.0 mg/kg; aldrin, dieldrin, endrin, heptachlor (including heptachlor epoxide), chlordane, lindane, benzene hexachloride, toxaphene, and endosulfan – 0.1 mg/kg, either singly or in combination.*

Aquatic life should be protected where the maximum concentration of total PCB in unfiltered water does not exceed 0.002 µg/L at any time or place, and the residues in the general body tissues of any aquatic organism do not exceed 0.5 µg/g."

Table 6
Recommended Maximum Concentrations of Organochlorine Pesticides in Whole (Unfiltered) Water, Sampled at Any Time and Any Place

Organochlorine Pesticides	Recommended Maximum Concentration (µg/L)	Suggested Values for Tissue Residues (mg/kg), wet weight
Aldrin	0.01	0.1
DDT	0.002	1
TDE	0.006	
Dieldrin	0.005	0.1
Chlordane	0.04	0.1
Endosulfan	0.003	0.1
Endrin	0.002	0.1
Heptachlor	0.01	0.1
Lindane	0.02	0.1
Methoxychlor	0.005	
Toxaphene	0.01	0.1
PCBs	0.002	0.5

Source: NAS/NAE (1973)

The senior author of this report (G. Fred Lee) was an invited peer reviewer to the NAS/NAE for the "Blue Book" water quality criteria. He is, therefore, familiar with how these criteria were developed and the considerable uncertainty associated with critical tissue residue levels for protection of aquatic life in higher-trophic-level organisms. Upon learning that the SWRCB and the Regional Boards were using these values in evaluating excessive bioaccumulation of chemicals in fish tissue, he contacted the Chair of the Blue Book water quality criteria committee (Carlos Fetterolf), the National Academy of Sciences, the US EPA, and others to obtain their assessment of the reliability of the suggested critical tissue residues presented in the Blue Book (which were largely based on 1960s information) as appropriate for use today to judge excessive concentrations of bioaccumulatable chemicals in aquatic life.

The chairman of the NAS/NAE (1973) Blue Book Criteria Committee (Fetterolf, pers comm., 1996), who was also former chief biologist for the state of Michigan water pollution control program and former executive secretary of the Great Lakes Fisheries Commission, indicated that it is inappropriate to use the 1972 "NAS" Blue Book values as being reliable today for estimating excessive concentrations of chemicals in aquatic life tissue. The US EPA, any state other than California, and the National Academy of Sciences do not recognize the "NAS" values used by the SWRCB and the Regional Boards as reliable screening values for determining excessive concentrations of chemicals in aquatic organism tissue.

The National Academy of Sciences Committee on Evaluation of the Safety of Fishery Products, Food and Nutrition Board, Institute of Medicine, staff member F. Ahmed was contacted regarding whether the NAS recognized the NAS/NAE Blue Book of fish tissue guidelines. While the NAS has published a book on Seafood Safety (Ahmed, 1991), Ahmed did not know that the 1972 Blue Book so-called "guidelines" existed, and indicated that they are not recognized by the NAS as being reliable today.

A comparison between the late 1960/early 1970 state of information on the critical concentrations of OCls to cause aquatic life toxicity, as shown in Table 6, and the CTR criteria, shown in Table 2, shows that there have been significant changes in a number of these values. This is to be expected, based on the large amount of work that has been done since the late 1960s in relating the concentrations of chemicals to their effects on aquatic life. Ankley (pers. comm., 2002), of the US EPA National Health and Environmental Effects Research Laboratory Mid-Continent Ecology Division, Duluth, MN, has commented that, *"The fact that the values are the same (0.1 mg/kg) for whole host of OCs with differing mechanisms of action should be a tip off as to how reliable they may be."* Dr. Ankley is an internationally recognized expert on aquatic organism health effects of tissue residues.

As part of developing regulatory approaches for disposal of contaminated dredged sediments, the US Army Corps of Engineers (US ACOE, 1997) developed "The Environmental Residue-Effects Database (ERED)." This database is a compilation of information on the concentrations of chemicals in aquatic organism tissue and their apparent effects on aquatic life. The ERED is available electronically from http://ered1.wes.army.mil/ered/index.cfm. It was last updated June 2001. It now contains 3,463 results of 736 studies on 188 species for 222 analytes.

The issue of critical concentrations of bioaccumulatable chemicals in aquatic life tissue is one that has been addressed by the US EPA. Jarvinen and Ankley (1999) have published a review, <u>Linkage of Effects to Tissue Residues: Development of a Comprehensive Database for Aquatic Organisms Exposed to Inorganic and Organic Chemicals</u>. This publication presents a comprehensive, critically-reviewed, literature-based assessment of the concentrations of chemicals found in aquatic organisms relative to observed effects on the organisms. The Jarvinen and Ankley (1999) database has well over 3,000 entries for 200 chemicals, and is based on 500 references. The organochlorine pesticide database includes 15 organochlorine pesticides, with 473 endpoints and 91 references, representing 68 aquatic species, 46 of which were freshwater.

Appendix B presents an excerpt from the Jarvinen and Ankley (1999) review for the concentrations of DDT and other legacy pesticides and PCBs in whole organisms and the associated effects on the organism. The Jarvinen and Ankley toxicity/residue database as published by SETAC press is available in an Access database format at the web site http://www.epa.gov/med/databases/tox_residue.htm. Examination of Appendix B shows that there is a wide range of values of DDT concentrations in fish and other aquatic life that have been found to be adverse to the host organism. A comparison between the information presented in Appendix B for DDT residue concentrations relative to effects on aquatic life and the "NAS" guideline value presented in Table 6 shows that there are concentrations well above the guideline value that have been found to not be adverse to aquatic life. There are also situations where concentrations below the "NAS" value were adverse. The conclusion is that the "NAS" values are not reliable values for evaluating the potential impacts of OCls on aquatic life that host the OCl residue, or higher-trophic-level organisms that use the residue host as food.

US EPA Great Lakes Water Quality Initiative. In the 1980s the US EPA (1990a,b), as part of the Canadian/US Great Lakes water quality program, conducted comprehensive reviews of the critical concentrations of various chemicals to aquatic life and wildlife. One of the issues addressed was the relationship between water concentrations of potential pollutants and the concentrations that are adverse to wildlife through eating fish that have bioaccumulated the pollutant. The US EPA developed a rigorous approach for developing water quality criteria for protection of wildlife (US EPA, 1990b, 1995c). The US EPA concluded that there was sufficient information to justify developing water quality criteria for PCBs, DDT, mercury and dioxins that are designed to protect wildlife and birds that use Great Lakes fish as food. The latest information on these criteria is provided in US EPA (2000c). The criterion for PCBs is 1.2×10^{-4} µg/L. For DDT, it is 1.1×10^{-5} µg/L. For 2,3,7,8-TCDD (a form of dioxin), it is 3.1×10^{-9} µg/L. A comparison to the "NAS" PCB criterion for protection of wildlife (0.002 µg/L) shows that the Great Lakes Initiative criterion is about an order of magnitude lower than the "NAS" criterion. For DDT the Great Lakes Initiative value is about 2 orders of magnitude lower than the "NAS" .value (0.002 µg/L). There was not sufficient information, however, to develop wildlife-based water quality criteria for the other OCls. Further, while the US EPA did use a number of more recent "NAS" guidance values in developing the Great Lakes Initiative criteria, the Agency did not use the "NAS" (1973) Blue Book values as appropriate criteria for protection of OCl host organisms and higher-trophic-level wildlife.

The senior author was involved in Great Lakes water quality issues for about 20 years. During this time he became familiar with the behavior of various OCls in the Great Lakes waters. It became clear that a single OCl water quality criterion was not appropriate for all of the Great Lakes. Each Great Lake behaved differently with respect to how an OCl, such as a pesticide or PCBs, bioaccumulated and impacted aquatic life. This was related to the trophic state (algal biomass) of the waterbody. The lower Great Lakes, Erie and Ontario, which are much more productive waterbodies, could have much higher concentrations of OCls without excessive bioaccumulation or toxicity than the upper Great Lakes (Superior, Michigan and Huron).

It would be inappropriate to use the Great Lakes Initiative wildlife-based water quality criteria in Central Valley waterbodies because of the large amounts of suspended solids for waterbodies compared to the upper Great Lakes, which served as the basis for the Great Lakes Initiative wildlife criteria. As a result, at this time, there are no valid water quality criteria or tissue residues that can be used to determine excessive concentrations in the water column or in aquatic organisms that would be protective of host organisms and higher-trophic-level organisms.

OCl Management Goals

There are several regulatory limits that can be used as OCl excessive bioaccumulation management goals, the most important of which are the OEHHA screening values (Table 4) for determining excessive edible fish tissue concentrations for each of the OCls of concern in this OCl management guidance. In addition, there are the US EPA water quality criteria (Table 2) and the US EPA and OEHHA drinking water MCLs (Table 3), which are appropriate TMDL goals for water column concentrations of the OCls. While some agencies propose to use co-occurrence-based sediment quality guidelines as an OCl TMDL target, as discussed herein, this approach is technically invalid since there is no reliable relationship between the co-occurrence-based sediment quality guidelines and the concentrations in sediments of bioavailable forms of the OCls that bioaccumulate to excessive levels in edible fish and other aquatic life.

The management goal to control excessive bioaccumulation of OCls should be based on critical tissue residues to protect those who use the fish as food from increased cancer risk. The OEHHA values listed in Table 4, when adjusted for site-specific fish consumption rates for the listed Waterbody, are the recommended management goals for the Waterbody. Since site-specific consumption rates are not now available, there is need to develop this information so that an appropriate OCl bioaccumulation management program can be developed for the listed Waterbodies.

Since regulatory agencies need to establish critical concentrations of a chemical in water and/or sediments as part of implementing a regulatory program to control beneficial use impairment, there is need to establish first-cut, site-specific critical sediment concentrations of each of the OCls that cause a 303(d) listing and allowed loading for each of the listed Waterbodies. The co-occurrence-based so-called "sediment quality guideline" values should not be used for this purpose because of their obvious unreliability. Instead, site-specific sediment biota accumulation factors should be developed which relate the listed Waterbody's allowable edible tissue residues to the sediment-associated bioavailable forms of the OCls of concern. The approach used should follow US EPA guidance (discussed herein) for establishing sediment-associated bioavailable forms involving incubation of *Lumbriculus variegatus* in the sediments.

The site-specific biota accumulation factors for each of the listed Waterbodies or parts thereof can be used as an initial estimate of the degree of sediment remediation/source control needed to achieve the Waterbody-specific allowable OCl fish tissue residue. It should be understood that the initial waterbody site-specific sediment biota accumulation factor will likely need to be adjusted as additional information is obtained and especially during the course of a source control and/or sediment remediation program. Further, there will likely be need for large waterbodies, such as the Delta, Sacramento River, San Joaquin River, etc., to develop specific information for parts or reaches of the waterbody to relate bioavailable forms in the sediments and from sources to tissues of edible fish taken from each of the reaches of the waterbody.

Critical Sediment OCl Concentrations. It was established in the 1960s, through work on the concentrations of potentially toxic chemicals in sediments through measured toxicity, as well as the extent of bioaccumulation of the sediment-associated chemical in aquatic life, that the total concentration of a chemical in sediments is an unreliable indicator of its potential impacts on aquatic life. During the 1970s, the authors of this report (G. F. Lee and A. Jones-Lee) and their associates conducted about $1 million in research on the water quality significance of about 30 chemicals in U.S. waterways' sediments taken from approximately 100 locations across the United States (see Lee, *et al.,* 1978, and Jones and Lee, 1978). A summary of this work has been published by Lee and Jones-Lee (2000). These studies included measurement of the OCls of concern in this TMDL guidance report in water, sediments and aquatic life. These studies documented what was known before they were initiated, that the total concentration of an OCl, heavy metal, or many other constituents in sediments was not related to its biological effects or tendency to be released to the water column.

During the 1970s, under contract with the Corps of Engineers, Dr. G. Fred Lee conducted studies of the release of organochlorine pesticides and PCBs from sediments for about 100 different U.S. waterways. He found that PCBs were most readily released to the water column from sediment suspension when the sediments had a low petroleum hydrocarbon content. This release was not necessarily related to the total organic carbon (TOC) content of the sediments. Sediments with low petroleum hydrocarbon content, which are typically sandy type sediments, such as obtained several miles out in the Gulf of Mexico near Galveston, Texas, readily released a substantial portion of the PCBs present in the sediments during suspension of the sediments in the water column. Sediments with high petroleum hydrocarbon content which had much higher concentrations of PCBs (taken from the Houston Ship Channel) released little of the PCBs upon suspension into the water column.

Equilibrium partitioning is an approach developed by the US EPA to relate the release of certain chemicals bound to sediments to the interstitial waters associated with the sediments. In the early 1990s it was thought that equilibrium partitioning between the sediment TOC and the OCl dissolved in the interstitial water could be used to regulate the concentrations of certain chemicals such as OCls in sediments, with respect to their potential to be toxic to aquatic life. For further information on equilibrium partitioning, consult US EPA (2002e).

Based on the authors' studies, which included measurement of sediment TOC and the release of OCls upon suspension of the sediments and their associated interstitial water in an elutriate test, it is clear that equilibrium partitioning with TOC is not the only mechanism controlling PCB release. Release is dependent not only on the TOC content, but on the type of organics that make up the TOC. Sediments with high petroleum hydrocarbon content bound OCls more strongly per unit organic carbon than sediments with the same TOC but low petroleum hydrocarbons. How this relates to bioaccumulation, which is the other important process governing the transfer of PCBs from sediments to aquatic organisms through the food web, is not well understood. This has been a long-standing issue that still has not been adequately addressed. It is of importance in determining the appropriate approach to take for sediment remediation for controlling OCl excessive bioaccumulation.

The authors and their associates' studies served as a foundation for the US Army Corps of Engineers and the US EPA to develop a biological-effects-based approach for regulating the disposal of chemically contaminated dredged sediments. In the late 1970s, the US EPA and Corps developed dredged sediment evaluation manuals for freshwater and marine systems that relied on measurements of aquatic life toxicity and bioaccumulation in aquatic organisms as a means of evaluating the potential water quality significance of chemical constituents in aquatic sediments. These manuals have been updated as US EPA/US ACOE (1991, 1998).

Unreliability of Sediment Co-Occurrence-Based Approaches. Beginning in the 1980s, several individuals ignored the well-established fact that the total concentration of a constituent in sediments is an unreliable predictor of aquatic life toxicity. The most notable of the inappropriate approaches that have been advocated for evaluating sediment quality is the co-occurrence-based approach first developed by Long and Morgan. Long and Morgan (1990) proposed co-occurrence-based sediment quality "guidelines" to predict the impact of sediment-associated chemicals on aquatic life living within or upon sediments. The co-occurrence-based approach as used by Long and Morgan and others such as MacDonald (1992) involves compiling sets of sediment data that contain some information on sediment biological characteristics, such as laboratory measured toxicity, or benthic organism assemblages (numbers and types of organisms) and the **total** concentration of potential pollutants. The potential pollutants are those that are typically considered in water quality assessments that have been found in some other non-sediment-related situations to be toxic to aquatic life. The literature reported concentrations are ranked according to increasing concentration. The sediment concentration which has a so-called "effect" is used to develop a co-occurrence between a sediment chemical concentration measured as a total concentration and a water quality "effect."

Lee and Jones-Lee (1996a,b) have provided a detailed discussion of the lack of technical validity of the co-occurrence-based approach for evaluating sediment quality. As they point out, this approach has a number of inherent, invalid assumptions. First, the approach presumes that there is a causal relationship between the concentration of each contaminant considered in sediment and the water quality impact of that sediment. Second, it presumes that the "effect" reported for each sediment was caused independently by each of the measured chemical contaminants in that sediment. Third, it presumes that no other chemical or condition not included in the database has any influence on the manifestation of the "effect" that co-occurs with the particular chemical of focus; ignored are several sediment-associated contaminants and conditions that are well-recognized to cause aquatic life toxicity, including ammonia, hydrogen sulfide, and low dissolved oxygen. Fourth, it presumes that the assessments made of "effects" of the sediments relate in some meaningful way to adverse impacts on beneficial uses of the waterbody in which the sediments are located.

In regulatory applications, co-occurrence information has been used or proposed for use, albeit incorrectly, to establish various "effects threshold" values. That is, applying statistics to the ranked listing of co-occurrence information of a given chemical, it was determined for that data set the concentration of the chemical that has a given probability of co-occurring with an impact, or the lowest concentration with which "no effect" co-occurred for that set of sediments. Examples of these approaches are the "Apparent Effects Threshold" (AET), and numeric values developed from Long and Morgan's (1990) data presentation in the form of ER-L and ER-M values, and "Probable Effects Levels" (PEL) values derived from MacDonald's (1992) co-occurrence compilations. If a sediment contains a chemical in concentrations above the AET, PEL, or similar value, the sediment is considered by some regulators or proposed regulations to be "polluted," and to require special consideration such as "remediation," alternate methods of dredged sediment disposal, or control of permitted discharges to the waterbody of a chemical that accumulates in the sediments.

As discussed by O'Connor (1999a,b, 2002), O'Connor and Paul (2000), O'Connor, *et al.* (1998), Engler (pers. comm.), Ditoro (2002), Chapman (2002), Burton (2002), Lee and Jones (1992), and Lee and Jones-Lee (1993; 1996a,b; 2000, 2002), the co-occurrence approach is not a technically valid approach for assessing the potential impacts of chemical constituents in sediments. It has been well-known for over 30 years that the total concentration of a chemical constituent in sediments is not a valid measure of the toxic/available forms of constituents that can impact aquatic life through toxicity or cause other impacts. Further, and most important, co-occurrence is not a valid basis for simple systems with a limited number of constituents for evaluating the cause of a measured impact. Co-occurrence is obviously not valid for relating the concentrations of sediment-associated potential pollutants to observed laboratory-measured toxicity or altered organism assemblages in which the chemical constituent of concern is measured. In normal situations, there is no valid cause-and-effect relationship between the total concentration of a chemical constituent in a sediment and its responsibility for some measured "impact."

As more and more data were accumulated that showed that the Long and Morgan and MacDonald guideline values were not reliable predictors of sediment toxicity and other impacts, Long and his associates tried to improve the reliability of the co-occurrence-based approach by using the normalized summed quotients for several chemical constituents to establish the value for comparison with the biological characteristic of the sediments determined by their co-occurrence evaluation. While not discussed by Long and Morgan and others who advocate this approach, the magnitude of the normalized summed value depends on the constituents included in the data review. While for highly degraded areas there is some claimed success for the expanded approach, the expanded co-occurrence approach is also not valid to relate the concentration of a single chemical constituent or a group of constituents' impacts on sediment and overlying water quality/beneficial uses.

Even though it is well-recognized that the Long and Morgan (and, subsequently, MacDonald) co-occurrence approaches are not valid tools to evaluate the potential significance of a chemical constituent in a sediment, there is continuing use of the co-occurrence-based guideline values as regulatory goals upon which control programs, such as TMDLs, are based. This arises from a lack of knowledge and understanding of sediment chemistry and toxicology/biology by those who are responsible and/or interested in sediment quality management.

Those who advocate use of co-occurrence-based sediment guidelines frequently claim that there are insufficient funds available to conduct the needed biological-effects-based evaluation of sediment chemistry and toxicology/biology to properly evaluate the water quality significance of a constituent in sediments. Since total chemical concentration data are frequently available for sediments, and since co-occurrence approaches superficially seem to provide a way to use these data in sediment quality evaluation, the co-occurrence-based approach receives use by regulatory agencies in order to provide some "information" on sediment quality without having to spend any significant amount of additional funds in sediment quality evaluation. There is also a strong desire by some to do something in addressing sediment quality even if there is an inadequate technical information base to enable a reliable sediment quality evaluation to be made. Such an evaluation would require detailed study of the sediments' aquatic chemistry/toxicology/biology.

One of the most significant recent inappropriate uses of co-occurrence-based approaches for regulating sediment quality has been proposed by the US EPA (2002c) Region 9. The Agency used the Buchman (1999) "NOAA Screening Quick Reference Tables (SQuiRTs)" to obtain TMDL targets for managing excessive bioaccumulation of organochlorine pesticides and PCBs in Upper Newport Bay, Orange County, CA, and its tributary San Diego Creek. The organochlorine chemicals of concern (for which there is excessive bioaccumulation in the Upper Newport Bay and its tributaries) are chlordane, dieldrin, DDT, PCBs and toxaphene. In discussing numeric targets for organochlorine TMDLs, the US EPA (2002c) states,

> *"As discussed in Section II, EPA evaluated the applicable water quality criteria and sediment and tissue screening levels to determine the appropriate numeric targets for these organochlorine TMDLs. We have prioritized sediment quality guidelines over tissue screening values and water column criteria. This decision is based on the following factors:*
>
> 1) *these pollutants are directly associated with sediments (i.e., fine particulate matter);*
> 2) *sediments are the transport mechanism for these organochlorine compounds from freshwaters to salt waters;*
> 3) *limited water column data are available to adequately describe the past or current conditions; and*
> 4) *attainment of the sediment targets will be protective of the water column criteria and tissue screening values."*

This approach and the reasoning in support of it are fundamentally flawed from several perspectives. First, the so-called "NOAA SQUIRT values" are co-occurrence-based values that evolved out of the Long and Morgan and MacDonald work. The biological effect used to establish these values did not consider bioaccumulation. Further, critical human health bioaccumulation concentrations in edible fish are frequently far below any concentration that is adverse to the host organism (fish). There is no relationship between the co-occurrence values of Long and Morgan and MacDonald and the potential for a chemical constituent in sediments to bioaccumulate to excessive levels in edible fish tissue.

With respect to the first and second justification listed above in support of this approach, the fact that a chemical tends to become associated with sediments is not justification for using co-occurrence to predict excessive bioaccumulation. As far as the validity of the third justification, those familiar with bioaccumulation situations know that measurement of constituents of concern in the water column is not a reliable approach for predicting the bioaccumulation of organochlorine pesticides, PCBs, dioxins, etc. With respect to the fourth justification in support of this technically invalid approach, because of its fundamental unreliability, it is inappropriate to say that it is either under- or over-protective.

There is no reliable way to relate sediment concentrations of organochlorine pesticides and PCBs to excessive bioaccumulation of these chemicals in edible fish tissue except through site-specific studies. This issue is discussed in a subsequent section. The US EPA Region 9 has made a serious error in using the Buchman SQUIRT co-occurrence-based values. This approach should be immediately abandoned in favor of fish tissue target values developed by the CA Office of Environmental Health Hazard Assessment. These values are appropriate TMDL goals for managing the excessive bioaccumulation of organochlorine pesticides and PCBs.

The approach that should be followed in evaluating the water quality/sediment quality significance of a chemical constituent in sediments was defined by the US EPA and the Corps of Engineers in the 1970s for regulating contaminated dredged sediments. As discussed above, the US EPA/US ACOE (1991, 1998) developed dredged sediment quality evaluation manuals which provide detailed guidance on determining whether the management of a contaminated dredged sediment in a particular manner will impact water quality of the receiving waters where the management/disposal of the dredged sediment takes place. These agencies used a biological-effects-based approach rather than a chemical-concentration-based approach – e.g., rather than measure copper in the sediments and then speculate about the copper toxicity and its sediment/water quality impacts, the US EPA/US ACOE approach measures toxicity and then uses Toxicity Investigation Evaluations (TIEs) to determine its cause.

Lee, *et al.* (2002), associated with their work on the role of PCBs in city of Stockton Smith Canal sediments as a source of PCBs that are bioaccumulating to excessive levels in Smith Canal fish, reviewed the literature on the approach that should be used to relate sediment concentrations of OCls to aquatic life tissue residues. Presented below are excerpts from the US EPA (2000b) which provides additional information on this issue. Also see discussion of this issue by Lee, *et al.* (2002) in their Smith Canal PCB report.

Theoretical Basis for Bioaccumulation from Sediments. The US EPA (2000b) report, "Bioaccumulation Testing and Interpretation For the Purpose of Sediment Quality Assessment: Status and Needs," provides important background information on the use of bioaccumulation tests to evaluate whether contaminated sediments pose an ecological and/or human health risk. As discussed in this report,

> *"The bioavailability of contaminants in sediment is a function of the type of chemical and the chemical speciation, as well as the behavior and physiology of the organism. The two basic routes of exposure for organisms are transport of dissolved contaminants in pore water across biological membranes, and ingestion of contaminated food or sediment particles with subsequent transport across the gut. For upper-trophic-level species, ingestion of contaminated prey is the predominant route of exposure, especially to hydrophobic chemicals [such as the organochlorine pesticides and PCBs]."*

Brower and Cecchine (2002) have just published a review on the bioavailability of chemical constituents in aquatic sediments. The bioavailability of organochlorines is controlled to a major extent through partitioning between the chemical constituent and organic matter. Those constituents with high octanol water partition coefficients (Kow) tend to bioaccumulate to a greater degree, especially in organisms with higher lipid content. The US EPA (2000b) presents a discussion of the theoretical basis for bioaccumulation of chemicals like PCBs and the organochlorine pesticides from sediments. The following section is an extract from this report.

> 3.3.2.3 Biota-Sediment Accumulation Factors
> In USEPA (1995a), BSAFs are defined as the ratio of a substance's lipid-normalized concentration in tissue of an aquatic organism to its organic carbon-normalized concentration in surface sediment, in situations where the ratio does not change substantially over time, both the organism and its food are exposed, and the surface sediment is representative of average surface sediment in the vicinity of the organism.
>
> Site-specific BSAFs (kg of organic carbon/kg of lipid) are calculated for nonpolar organic compounds using the formula
>
> BSAF = (Ct/f1) / (Cs/foc) (4)
>
> where Ct is the contaminant concentration in the organism (both wet and dry weight are commonly used, so moisture content should be provided whichever is used, as well as a clear delineation of which is selected), f1 is the lipid fraction in tissue, Cs is the contaminant concentration in sediment (generally dry weight), and foc is the organic carbon fraction in sediment. This lipid-normalized relationship was developed for neutral (nonionic) organic compounds and is not appropriate for inorganic substances (e.g., metals), although it has been applied to tributyltin (Eisler, 1989). This relationship is not applicable to methylmercury because methylmercury binds tightly to tissue macromolecules (Spacie *et al*., 1995; Bridges *et al*. 1996).

One of the basic premises of equilibrium-based modeling as related to sediments is the equilibrium partitioning theory (DiToro *et al*., 1991). This theory is being used to propose sediment quality guidelines for two nonionic organic compounds (e.g., USEPA, 1994a), as well as for PAH mixtures and metals mixtures. The essence of the theory is that concentrations of hydrophobic chemicals in sediments are more predictive of biological effects when they are normalized to sedimentary organic carbon. Through this normalization, the concentration of these compounds in the pore water can be predicted based on Equation 5. Evidence to date indicates that chemicals that are freely dissolved in the pore water are more bioavailable than chemicals sorbed to sediments. Thus the pore water concentration, as measured or as predicted through equilibrium partitioning, is a better predictor of bioaccumulation than concentrations of chemicals on a dry weight basis in the sediment (DiToro *et al*., 1991).

Cw = Cs/focKoc (5)

where Cw is the freely dissolved concentration of nonionic chemical compound in pore water, Cs is the concentration of the chemical in the sediment, foc is the fraction of sedimentary organic carbon, and Koc is the organic carbon-water partition coefficient (which can be related to Kow).

As with BAFs, BSAFs are typically derived on a site- and species-specific basis, using empirical data (USEPA, 1992). Therefore, they incorporate the effects of metabolism, biomagnification, growth, and bioavailability. BSAFs can also be used to estimate BAFfd, as described in Cook *et al*. (1993) and USEPA (1995a), where BAFfd is defined as follows, where Cfd is the freely dissolved concentration of a contaminant in water:

BAFfd = Ct/Cfd (6)

Accurate information on organism lipid content and sediment TOC content is required to calculate a BSAF. Lipid content can vary considerably within a single species, based on life stage, sex, and season, so caution is necessary when attempting to use site- or species-specific BSAFs as predictors of tissue burdens in different systems. As with BAFs, proper calculation requires a reasoned approach regarding species exposure, including movement and life history as well as spatial and temporal trends.

BSAFs are most directly applied to infaunal organisms with known home range. For example, Lake *et al*. (1990) found that analysis of PCBs in mollusks and polychaetes at field sites representing a range of TOC and contaminant concentrations showed that BSAF calculations (i.e., lipid- and TOC-normalized concentrations) significantly reduced the variability in the raw tissue-sediment data relative to non-normalized data. Work by Hydroqual, Inc. (1995), however, has shown that lipid normalization does not always decrease the variability in BAFs (or BSAFs) and that the decision to lipid normalize and the method by which lipid normalization is achieved depend on species-specific factors as well as lipid contents.

Since ecosystems are rarely in equilibrium, BSAFs include an inherent measure of disequilibrium of the system, which can be quantified as described in USEPA (1995a). Disequilibrium is caused by kinetic limitations for chemical transfer from sediment to water, sediment to biota, or water to the food chain, as well as biological processes such as growth or biotransformation (USEPA, 1995a). Theoretically, at equilibrium BSAFs range from 1 to 4 since the ratio of Kl to (Kl/Ksoc) is thought to range from 1 to 4, where Kl is defined as the lipid-water equilibrium partition coefficient and Ksoc is defined as the sediment organic carbon-water equilibrium partition coefficient (USEPA, 1995a). However, since most systems are not at equilibrium, a wider range of BSAFs is reported. This wider range of BSAFs measured in the field does not invalidate the concept. On the contrary, it underlines the need for a field-measured BSAF that is able to incorporate disequilibrium processes (as well as exposure conditions). Several compilations of BSAFs are available, including Lee (1992), Boese and Lee (1992), and Parkerton *et al*. (1993), as well as a USACE Contaminants Database accessible via the Internet (McFarland and Fergusen, 1994).

The use of site-specific BSAFs using techniques described in USEPA (1994b) is preferred. However, if literature values are used, available options include selecting a given percentile of the BSAF distribution (as in the TBP method, which uses the 94th percentile) (McFarland and Ferguson, 1994) or using a regression equation as in the proposed Washington State guidance for sediment quality criteria for human health (PTI, 1995).

BSAFs are most useful for systems that are in steady state, which is technically defined as concentrations in sediment, water, and organisms that do not change as a function of time even though they may not reflect a thermodynamic equilibrium distribution between sediment, water, and organisms. In a practical sense, systems are often considered steady state if the concentrations do not change within the period of study. Therefore, the use of BSAFs to predict tissue concentrations might not be reliable in situations in which the chemical of interest is rapidly degraded or inputs of the chemical to the system vary. In these instances, kinetic models might be more appropriate (see Section 3.3.3.1).

Hydroqual, Inc. (1995) has developed a database of field-measured bioaccumulation factors for a variety of superhydrophobic compounds. Part of this effort involved development of a procedure whereby BAFs or BSAFs could be predicted for previously unstudied chemicals, species, or water bodies. Hydroqual concluded that within a homogeneous group of compounds (e.g., PCB congeners) BAFs and BSAFs can be predicted only within a factor of 10. The uncertainty arises from site- and species-specific differences in food web structure, partitioning at the base of the food web, and the physiology of the organisms, as well as measurement error (Hydroqual Inc., 1995). Predicting BAFs and BSAFs for chemicals outside the "homogeneous group" results in even greater uncertainty. However, results of chemical class-specific analyses in Tracey and Hansen (1996) revealed a similarity of BSAF values among species and habitat types.

The biota-suspended solids accumulation factor (BSSAF) has also been proposed for some studies. It is identical to the BSAF approach, with the exception that contaminant uptake by fish is from suspended solids, rather than in-place sediments (USEPA, 1994b). Its use has been limited.

3.3.2.4 Food Chain Multiplier

As discussed in Section 3.3.2.2, a BAF can be estimated from a BCF if the BCF is multiplied by a factor to account for food web transfer. This factor is referred to as a food chain multiplier (FCM) (USEPA, 1993a, 1995a).

$$BAF = (BCF)(FCM) \quad (7)$$

The FCM is defined as the ratio of a BAF to an appropriate BCF (USEPA, 1995a). It has been calculated in a variety of different ways, two of which are discussed briefly below. In both approaches, FCMs are calculated assuming metabolism is negligible. USEPA (1993a) calculates FCMs using a model of the stepwise increase in the concentration of an organic chemical from phytoplankton (trophic level 1) through the top predatory fish level of a food chain (trophic level 4) (Thomann, 1989). Thomann's model was used to generate BCFs and BAFs for trophic level 2 species (e.g., zooplankton) and BAFs for trophic level 3 and 4 species (small fish and top predator fish, respectively) over a range of chemicals with log Kow values from 3.5 to 6.5. At each log Kow value, FCMs were calculated as follows:

FCM2 = BAF2/BCF2 (8)
FCM3 = BAF3/BCF2 (9)
FCM4 = BAF4/BCF2 (10)

where FCM2, FCM3, and FCM4 are the food chain multipliers for trophic level 2, 3, and 4 species, respectively; BCF2 is the BCF for trophic level 2 organisms; and BAF2, BAF3, and BAF4 are the BAFs for trophic level 2, 3, and 4 species, respectively. Field-measured BAFs from the Great Lakes for trophic level 4 were found to be within an order of magnitude of those predicted using this approach (Thomann, 1989; USEPA, 1993a). At log Kow values of 6.5 and greater, the relationship was less certain.

The FCM is defined below as given in USEPA (1995a), where BAFfd is predicted using the Gobas (1993) bioaccumulation model. In the Gobas (1993) model disequilibrium, as discussed relative to BSAFs in the last section, is included in BAF predictions to some extent by inputting the measured concentrations of the chemical in the sediment and in the water column into the model (USEPA, 1995a).

This disequilibrium is then propagated through the food web model.

FCM = BAFfd/Kow (11)

The trophic level of an organism is needed when applying FCMs to determine BAFs. Trophic levels have traditionally been described in discrete terms as primary producers, primary consumers, secondary consumers, and top predators. Using this approach, trophic levels are symbolized by whole numbers. However, organisms have clearly defined or uniform food sources only in very rare circumstances. Typically, any organism higher in the food chain than primary consumers is likely at an intermediate trophic level, feeding on multiple trophic levels. As a result, attempting to model trophic transfer using linear food chain models introduces considerable variability into predictions of top predator tissue burdens.

Some methodologies have been developed to address trophic level issues. For example, Broman *et al*. (1992) have described a method to quantitatively estimate *in situ* biomagnification of organic contaminants that uses ratios of stable isotopes of nitrogen to classify trophic levels of organisms. Carbon and nitrogen isotopes are useful in characterizing an organism’s trophic level because animals’ metabolic processes tend to enrich the heavy isotopes of these elements, 13C and 15N (Peterson and Fry, 1987). Using this approach, significant enrichment of 15N in tissue relative to 15N in unmetabolized reference samples (i.e., in air) is indicative of increasing trophic levels.

Broman *et al*. (1992) have used the stable isotope approach to classify trophic levels in a littoral and a pelagic food web in the Baltic, as part of an attempt to study trophic transfer of dioxins and furans in that ecosystem. Based on their results, the authors have concluded that the isotopic method is a powerful tool for quantitatively estimating trophic biomagnification of a contaminant from field data at steady state. However, to evaluate non-steady-state conditions and the relative contributions of various exposure pathways, a more mechanistic approach, such as that described by Thomann (1989), is required. Stable isotope ratios can then be used in conjunction with a more mechanistic approach to provide more refined information on trophic pathways and consumption patterns.

It is apparent from the above discussion that factors governing bioaccumulation are far more complex than just a simple partitioning between the TOC in sediments and the lipid content of the organism tissue. This biota sediment accumulation factor relationship should be used with caution to provide an initial estimate of the sediment cleanup needed, with the understanding that it is, at best, a first approximation of the coupling between sediment concentrations and organism tissue concentrations. As the sediment concentrations changes, the coupling between the biota and the sediment will also likely change.

The US EPA (2000b,d) has provided guidance on measuring the bioaccumulation of potential pollutants in sediments using benthic organisms. This approach is a key component of developing the biota sediment accumulation factor.

The US EPA, in an effort to improve the ability to relate sediment concentrations to bioaccumulation, has developed the Bioaccumulation and Aquatic System Simulator (BASS) model. This model uses a dynamic modeling approach to relate sediment concentrations to food web biota concentrations of hazardous chemicals like PCBs. It considers the structure of the food web, as well as the biodilution associated with higher-trophic-level organism growth. This modeling approach overcomes many of the inherent problems with the biota sediment accumulation factor approach for relating sediment concentrations to aquatic life tissue residues. One of the primary benefits that can be derived from using this model is the ability to predict the rate of recovery of fish tissue residues associated with a sediment remediation program. It will be important, in conducting future studies on Central Valley bioaccumulation of OCls in waterbody fish, to become familiar with this model, in order to include collection of the information needed to facilitate its use. Information on this model is available from Barber, *et al.* (2002).

The appendix of the US EPA (2000b) manual, "Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment," contains information on the characteristics of a number of chemicals of concern that tend to bioaccumulate. There is information on several PCBs and organochlorine pesticides. A review of this information shows, however, that it is not possible with the current information base to predict the magnitude of bioaccumulation that will occur in test organisms or higher-trophic-level organisms, including edible fish.

The results of the Lee, *et al.* (2002) city of Stockton Smith Canal sediment PCB bioavailability study provide information on the approach that should be used to assess the water quality impacts of sediment-associated OCls. White catfish and largemouth bass taken from Smith Canal in the city of Stockton have been found to contain sufficient concentrations of PCBs to be a threat to cause cancer in those who use these fish as a regular source of food. These fish contained about 100 ng/g wet weight of the PCB Aroclors, which is about five times the allowed OEHHA screening value for protection of humans who use PCB-contaminated fish as food. This finding has prompted a pilot study of the potential role of the Smith Canal sediments as a source of the PCBs that are bioaccumulating to excessive levels in edible Smith Canal fish. It has been found that a Yosemite Lake (which is located at the upstream end of Smith Canal) sediment sample contained about 1,000 ng/g dry weight of PCB congeners and Aroclors. Samples of Smith Canal sediments taken at about midway between Yosemite Lake and the mouth of Smith Canal ("Mid") contained about half (400 ng/g) the PCBs as compared to the

Yosemite Lake sediments. The Smith Canal sediment taken near the mouth of the canal where it discharges to the San Joaquin River Deep Water Ship Channel ("Mouth") had a lower concentration (12 ng/g) of PCBs, indicating that the source of PCBs was likely from storm sewers that drain several areas of Stockton into Yosemite Lake.

The Yosemite Lake sediment sample had a total organic carbon (TOC) content of about 5.8%, with the Mid-Canal (3.5%) and Mouth (0.5%) sediments having lower TOC content. This elevated concentration of TOC would make the PCBs in Yosemite Lake sediments less bioavailable than those associated with lower levels of TOC. Incubation of *Lumbriculus* (an oligochaete-worm) in the Smith Canal sediment samples, following the US EPA standard bioaccumulation testing procedure, showed that at least some of the PCBs were bioavailable, with exposure to Yosemite Lake sediment resulting in a 310 ng/g concentration (wet weight) in the worms after the 28-day incubation period. Lower amounts of PCBs were taken up by this worm from the Mid (161 ng/g) and Mouth (72 ng/g) sediment samples. The elevated TOC concentration of the Yosemite Lake sediment sample did not prevent some of the PCBs in this location's sediments from bioaccumulating in the test worm.

While the Smith Canal sediments contained several OCl pesticides, especially chlordane and DDT, only chlordane (15 ng/g) and several of the DDT transformation products (123 ng/g) were taken up by *Lumbriculus* above the analytical method's detection limit. There was also uptake of nonochlor from the sediments to 6 ng/g. At this time the known primary bioaccumulation problem in Smith Canal is due to PCBs and does not include the OCl legacy pesticides.

The Yosemite Lake sediments were also found by Pacific EcoRisk to be toxic to the benthic amphipod *Hyalella azteca,* with 40% mortality in the 10-day test. The Mid and Mouth Smith Canal sediments were nontoxic to *Hyalella*. The US EPA Mid-Continent Ecology Division located in Duluth, MN (Norberg-King, 2002) found, in testing a split of the same Yosemite Lake sediment sample, about 60% mortality to *Hyalella*.

This pilot sediment bioaccumulation study has demonstrated that the US EPA standard bioaccumulation testing procedure is a useful, readily implementable approach to determine the bioavailability of potentially bioaccumulatable, sediment-associated chemicals. This testing procedure should become part of the procedures that are used in developing management programs for excessive bioaccumulation problems, where the sediments are a reservoir of the bioaccumulatable chemicals.

Further studies are needed to define the magnitude of the excessive PCB bioaccumulation problem in edible fish taken from Smith Canal. These include additional fish sampling to confirm and establish the magnitude of the excessive PCB bioaccumulation problem in Smith Canal. If confirmed, then a comprehensive sediment sampling and PCB analysis program should be conducted. Also, additional studies on the uptake of the PCBs by *Lumbriculus* from Yosemite Lake sediments should be conducted.

Forensic studies, using PCB analysis of existing storm sewer sediments from the city of Stockton, should be used to attempt to determine the source of the PCBs that have accumulated in Yosemite Lake sediments. A likely source was one or more industrial facilities that dumped/discharged PCBs in the Stockton storm sewer system. Another possible source was an electrical transformer spill of PCBs that entered the storm sewer system that conveyed the PCBs to Smith Canal.

One of the objectives of these additional Smith Canal studies should be to establish a site-specific biota sediment accumulation factor for the dominant edible fish species and the sediment taken from Yosemite Lake. This value will be important in determining the initial sediment remediation objective associated with a program to control the excessive bioaccumulation of PCBs in Smith Canal fish that are derived from Yosemite Lake sediments.

The Smith Canal pilot studies provide a model of the approach that should be followed to evaluate the OCl residues present in the listed Waterbodies' sediments as a source of the OCls that are bioaccumulating in the Waterbodies' fish.

Potential Fish Tissue OCl Goals for Human Health Protection[1]

The approach that should be used to establish an OCl excessive bioaccumulation management goal is to first establish the critical edible tissue residue for each of the listed Waterbodies. This critical residue would be based on OEHHA screening values adjusted for local site-specific fish consumption rates. Information on fish consumption rates, developed by Cooke and Karkoski (2001), is presented below.

An acceptable level of OCl in fish tissues can be calculated using equation (1):

$$\text{Acceptable level of OCl in fish tissue} = \frac{\text{Daily intake * Consumer's body weight}}{\text{Consumption rate}} \qquad (1)$$

Units in this equation are:

$$\mu\text{g OCl/g fish (mg/kg)} = \frac{\mu\text{g OCl/kg bwt/day * kg bwt}}{\text{g fish/day}}$$

Where:

OCl = organochlorine pesticide, DDT, PCB, or dioxin/furan
g = gram,
µg = microgram,
kg = kilogram
bwt = consumer's body weight

[1] This section on fish consumption rates is derived in part from Cooke and Karkoski (2001).

The acceptable daily intake is the quantity at or below which humans consuming the fish containing the OCl are expected to be protected from adverse effects.

The most difficult of the variables to define is the consumption rate. Of particular concern are local populations near an OCl-listed Waterbody, where individuals are using fish from the Waterbody as a major source of their food. An example of this type of situation is the studies on the consumption of fish from Clear Lake, California, where the concern was excessive mercury in the fish tissue. According to Cooke and Karkoski (2001),

> *"One small consumption study has been completed for members of the Elem Tribe and several neighbors of the Sulphur Bank Mercury Mine at Clear Lake (Harnly et al., 1997). Participants reported eating an average 60 grams per day (g/day) of Clear Lake fish, however, the average was heavily influenced by high consumption rates of a few individuals. Consumption rate of the 90th percentile of study participants was 30 g/day of Clear Lake fish. At least some participants ate commercial fish as well. Species consumed in the greatest amounts were catfish and perch. Consumption information for the general population at Clear Lake has not been collected."*

This type of situation could occur for individuals or groups of individuals consuming fish from the OCl-listed Waterbodies. At this time, however, there is no information on site-specific consumption rates for the OCl-listed Waterbodies. Cooke and Karkoski (2001) have presented a comprehensive review of fish consumption issues, which should be referred to for additional information on these issues.

As shown by equation (1), the listed Waterbody fish consumption rate can make a marked difference in the calculated allowable fish tissue concentration. This information for DDT is provided in Table 7. Table 7 shows that DDT tissue concentrations at OEHHA's screening value of 100 mg/kg would result in an advisory to not consume more than 30 meals of contaminated fish and shellfish tissue per month for 4-, 8-, and 12-ounce meal sizes, and no more than 23 meals per month for 16-ounce meal sizes.

It is evident that the allowable OCl tissue residue for edible fish is highly dependent on local waterbody fish consumption rates. It is recommended that, as part of developing the TMDL for the OCl-listed Waterbodies, representative fish consumption rates taken from each Waterbody be developed.

Table 7
Monthly Consumption Limits for Chronic Systemic Health Endpoints for the General Population-DDT

Chemical Concentration in Fish Tissue[a] mg/kg	Recommended Risk Based Consumption Limit (meals per month)[b]			
	4 oz. Meal (0.114 kg)	8 oz. Meal (0.227 kg)	12 oz. Meal (0.341 kg)	16 oz. Meal (0.454 kg)
<0.08	>30	>30	>30	>30
0.08	>30	>30	>30	29
0.09	>30	>30	>30	26
0.1 (OEHHA)	>30	>30	>30	23
0.2	>30	23	15	11
0.3	>30	15	10	7
0.4	23	11	7	5
0.5	18	9	6	4
0.6	15	7	5	3
0.7	13	6	4	3
0.8	11	5	3	2
0.9	10	5	3	2

Source: Adapted from SARWQCB (2000)

>30 + Although consumption of more than 30 meals/month is allowed, US EPA advises limiting consumption to 30 meals in 1 month (1 meal per day)

a Instructions for modifying the variables in this Table are found in Section 3.3 of US EPA's (1995a) report. Consumption limits are based on an adult body weight of 70 kg and using a Reference Dose (RfD) = 5 x 10^{-4} mg/kg/d. References of RfDs can be found in Section 5 of the US EPA (1995a) report. The detection limit is 1 x 10^{-4} mg/kg.

b Monthly limits are based on the total dose allowable over a 1-month period (based on the RfD). When this dose is consumed in less than 1 month (e.g., in a few large meals), the daily dose will exceed the RfD.

Chemical and Physical Properties

There is substantial literature on the physical, chemical and biological properties of organochlorine pesticides, PCBs and dioxins. One of the key references to work on this issue includes US EPA (1979). The Agency conducted a comprehensive review of "Water-Related Environmental Fate of 129 Priority Pollutants." Information is provided on aldrin, chlordane, DDT, endosulfan, endrin, heptachlor, heptachlor epoxide, hexachlorocyclohexane (including lindane), TCDD (dioxins/furans), toxaphene and PCBs. In general, the OCl legacy pesticides and PCBs are aromatic or heterocyclic organochlorine compounds of moderate molecular weight. They are highly persistent in the environment, although they are degraded fairly readily in sunlight. They have a low water solubility and high octanol water partition coefficient and, therefore, have a high sorption tendency, especially to organic particles.

Of particular significance as a sorption site in aquatic sediments is particulate organic matter, such as animal and plant detritus (particulate remains) that have accumulated in the waterbody's sediments. Further, sediment inorganic particles frequently contain coatings of organics which serve as a surface for sorption of the OCls.

This sorption of OCls on organics is an important phenomenon with respect to influencing their bioavailability for uptake through the food web to higher-trophic-level organisms. Chiou, *et al*. (1977) have discussed the relationship between the octanol water partition coefficient for several organochlorine pesticides and their tendency to partition into fish fat (lipids). Chiou (2002) has just published a new review Partition and Adsorption of Organic Contaminants in Environmental Systems. Kilduff, *et al*. (2002) have just published a review on the theoretical basis for sorption of organics on soils and sediments. Further, Bailey and White (1964, 1970) developed the original, now classic, reviews on the sorption of pesticides on soil particles. Cheng (1990), in the Soil Science Society of America publication, Pesticides in the Soil Environment: Processes, Impacts, and Modeling, has published several articles on factors influencing the transport of pesticides in soils and their interactions with sediments which influence their bioavailability for bioaccumulation in fish. The review by Brower and Cecchine (2002) on bioavailability of potential pollutants in sediments provides additional information on these issues. These (and other publications cited therein) provide a substantial literature on the environmental transport, fate and persistence of OCls in terrestrial and aquatic systems.

As discussed by Lee and Jones-Lee (1993; 1996b), there are several aspects of sorption of the OCls on sediment particles which make it difficult to predict the fraction of the OCls in sediments that is bioavailable. There are different forms of organics in sediments which influence bioavailability. There is also sorption on inorganic particles. In the early 1990s, the US EPA (1993a) attempted to develop an equilibrium partitioning approach for estimating the concentrations of OCls and other chemicals that could be present in sediment interstitial (pore) water. This approach was based on the partitioning between the dissolved phase and the sediment total organic carbon. While at one time it was thought that it may be possible to normalize the sediment-associated OCl concentrations based on the total organic carbon concentration in the sediments, it has been found that this approach is not necessarily reliable for predicting sediment pore water concentration, much less the bioavailable fraction of OCls in sediments. As a result, the US EPA has abandoned developing equilibrium-partitioning-based sediment quality criteria.

As discussed herein, the problems of trying to relate waterbody sediment concentrations, including those normalized based on total organic carbon, to biological effects, have led the US EPA (2000b,d) to develop standardized sediment bioaccumulation testing procedures. These procedures involve incubating a standard test organism in the sediments to determine the amount of the OCl accumulating within the organism's tissue.

Sources of OCls for Waterbodies

There are both agricultural and urban sources of the organochlorine legacy pesticides for surface waters of the Central Valley. Virtually any place where these pesticides have been used in the past is a potential source to Central Valley waterbodies. As part of the USGS NAWQA (National Water-Quality Assessment Program), studies were conducted in the early to mid-1990s in the Sacramento and San Joaquin River watersheds on the transport of the OCl pesticides from agricultural and urban areas to waterbodies. As discussed below, it was found then that there was transport of several of these pesticides from agricultural areas associated with particulate matter transport during stormwater runoff, as well as in tailwater releases from irrigated agriculture. There was also transport of DDT from the city of Sacramento in Arcade Creek stormwater runoff. At this time, Arcade Creek is an urban creek, which primarily drains residential areas in Sacramento. It was unclear, however, whether the DDT was derived from urban use or its use on agricultural lands which have subsequently been converted to urban area.

Agricultural Runoff/Discharges as a Source of OCls. As part of reporting on the results of the USGS NAWQA studies, Dubrovsky, *et al.*, (1998), based on Brown (1997) and Pereira, *et al.* (1996), reported that the concentration of organochlorine insecticides in aquatic organisms and bed sediments were the highest in the small western tributaries to the San Joaquin River and in the lower part of the San Joaquin River. Dubrovsky, *et al.* (1998), as part of the USGS NAQWA studies in the San Joaquin River watershed, reported that,

> *"Long-banned organochlorine insecticides* [such as DDT, toxaphene and chlordane] *continue to be transported to streams by soil erosion of contaminated agricultural fields, resulting in contamination of suspended sediment, bed sediment and aquatic organisms.*
>
> - *Concentrations of organochlorine insecticides, such as DDT, toxaphene, and chlordane, in tissues of clams and fish from the San Joaquin River and its western tributaries, were high relative to national values obtained in the 1970s and 1980s.*
> - *Concentrations of DDT compounds in fine-grain bed sediments and tissue samples are correlated, suggesting that bioaccumulation is taking place.*
> - *Most whole-water concentrations of p,p'-DDT, chlordane, dieldrin, and toxaphene exceeded chronic criteria for the protection of freshwater aquatic life.*
> - *Runoff from winter storms will continue to deliver a substantial load of sediment-bound organochlorine insecticides to the San Joaquin River, even if irrigation-induced soil erosion is reduced."*

The organochlorine insecticides were generally banned from further use in agricultural and urban areas in the 1970s, primarily based on their detrimental effects on wildlife. Brown (1997), as part of the USGS NAWQA studies, showed that there was a decrease in the concentrations of certain organochlorine pesticides from earlier measurements. These conclusions are based on studies conducted during 1992 through 1995. It is likely that this situation still prevails today, where there is a continuing (albeit, slow) decrease in the concentrations of OCls in waters receiving agricultural land runoff, although additional studies are needed to verify this. It is recommended that studies of the type conducted by USGS NAWQA in the early to mid-1990s be conducted again to verify that the transport of several organochlorine pesticides from agricultural and urban areas at potentially significant concentrations is still occurring.

Brown (1997) found a strong correlation between the concentration of DDT in tissue of clams and fish and in bed sediments, suggesting that bioaccumulation from the sediments was taking place. According to Dubrovsky, *et al*. (1998), the results of these comparisons indicate that, though these insecticide concentrations might be declining, they are adversely impacting aquatic organisms and, hence, other wildlife in the San Joaquin River, and will likely continue to do so for years to come.

The NAWQA studies included analyzing suspended sediment samples from westside tributaries (Orestimba Creek, Spanish Grant Drain, Olive Avenue Drain, Del Puerto Creek, Ingram Creek, Hospital Creek) for 15 organochlorine pesticides. The most frequently detected OCl pesticides during the winter storm runoff were p,p'-DDE, p,p'-DDT, p,p'-DDD, dieldrin, toxaphene and chlordane. Aldrin, endrin, mirex and lindane were also detected during the winter stormwater runoff. Lindane was also detected during the irrigation season.

Dubrovsky, *et al*. (1998) reported that the winter stormwater runoff transport of sediment-bound DDT was especially high from Orestimba Creek, Spanish Grant Drain, Olive Avenue Drain, Del Puerto Creek, Ingram Creek, Hospital Creek and in the San Joaquin River. The winter runoff loads were much higher than summer loads associated with irrigation tailwater discharges. This led the USGS (Dubrovsky, *et al*., 1998) to conclude that controlling irrigation-induced soil erosion will reduce the transport of organochlorine insecticides, but it will not eliminate organochlorine insecticides from the San Joaquin River, because of the transport during winter storms.

Dubrovsky, *et al*. (1998) found that the concentrations of several OCl pesticides were somewhat higher in the irrigation season tailwater discharges than during the winter stormwater runoff. They reported that the concentrations of p,p'-DDT, chlordane, dieldrin and toxaphene exceeded US EPA chronic criteria for the protection of aquatic life. They did not discuss the fact that comparing particulate pesticide concentrations, such as those measured, to the US EPA water quality criteria, would tend to significantly overestimate the toxicity to aquatic life, since sediment-bound pesticides tend to be nontoxic or, at least, significantly less toxic than the dissolved form, which was the basis for the criteria development.

Domestic Wastewater as an OCl Source. Another source of the organochlorine legacy pesticides and PCBs is domestic wastewaters. The CVRWQCB (2002) has indicated that the city of Stockton's domestic wastewater discharges to the San Joaquin River have been found to contain DDT above the US EPA water quality criterion. As part of obtaining a revised NPDES permit from the CVRWQCB, the city of Stockton submitted the results of their Priority Pollutant effluent monitoring for the period of 1994 through 2000. In general, one or two samples of the effluent were taken per year during this period. With the exception of a couple of values, all are reported as less than the analytical laboratories' detection limit (reporting limit). These analyses were done by City-selected certified commercial laboratories.

A comparison between the critical concentrations for impacts to aquatic life and the potential for bioaccumulation to excessive levels in edible fish tissue (see Table 2) shows that the City's analytical laboratories have used analytical methods that have detection limits that are often many orders of magnitude less sensitive than those needed to detect the OCl chemical at a critical concentration based on California Toxics Rule criteria (US EPA, 2000a). For example, in 2000, the City's selected commercial laboratory reported the DDT group concentration as <1 µg/L. The CTR criterion for chronic exposure to DDT is 0.001 µg/L, and the critical worst-case concentration to prevent excessive bioaccumulation of DDT is 0.00059 µg/L. Similar analytical detection limit problems exist for other OCls, such as PCBs, where the CTR criterion for prevention of excessive bioaccumulation is 0.00017 µg/L. The City's selected commercial laboratory detection limit for PCBs was 0.2 µg/L.

During the period for which data is provided (1994-2000), three different commercial laboratories were used by the City for the OCl analysis. All laboratories reported that they were using US EPA Method 608. The City's most recent laboratory which provided data (BSK) has the highest detection limits for the OCls of the laboratories that have been conducting analyses for the City. The laboratory that the City used in the mid-1990s, using the same Method 608, had detection limits about 100 times lower than the laboratory that the City used in 2000.

Because of the large discrepancies between the analytical detection limits being used by the city of Stockton and the concentrations that, under worst-case conditions, can bioaccumulate to excessive levels in ambient-water fish, there is a potential for excessive bioaccumulation to be occurring of some OCls in the receiving waters for the wastewater discharge that is due, at least in part, to the City's wastewater discharge of OCls. There could be appreciable dilution of the effluent in the receiving waters and still have excessive concentrations of some OCls in the receiving waters above the CTR worst-case criterion to prevent excessive bioaccumulation of certain OCls.

There is a significant problem in the OCl Priority Pollutant data that are being provided by the City in being able to detect excessive OCls in the City's wastewater effluent. It can be concluded that, while there have been some measured concentrations of DDT and other OCls above the detection limit for the analytical method used, there could be far more detections of excessive OCls in the City's wastewater effluent than has been reported.

A review (http://www.epa.gov/waterscience/methods/guide/608.pdf) of the capabilities of the US EPA Method 608 for detecting the OCls shows that the method detection limits range from about 0.002 µg/L for dieldrin to about 0.01 µg/L for various DDT species. A review of the 20th Edition of Standard Methods (APHA, *et al*., 1998), Method 6630 C, which is the method "… *applicable to determination of organochlorine pesticides and PCBs in municipal and industrial discharges*," which is similar to US EPA Method 608, shows that the detection limits presented are similar to those of US EPA Method 608.

It is concluded that the city of Stockton is not using adequate analytical detection limits for measuring organochlorine pesticides and some other organochlorine compounds in its wastewater effluent. This situation may be occurring with other cities' wastewater municipal discharges in the Central Valley, and, therefore, domestic wastewaters may be a source of OCls for Central Valley Waterbodies that are contributing to the excessive bioaccumulation of OCls in edible fish in some Central Valley Waterbodies.

Since the analytical methods available, even if used properly, do not have adequate detection limits to measure the organochlorine pesticides and PCBs at CTR criterion values for excessive bioaccumulation, there is need for a more sensitive approach to determine whether OCls are present in domestic wastewaters or other sources that are bioaccumulating to excessive levels in receiving-water fish. An approach that could be used would involve establishing a flow-through system, where part of the treated effluent would pass through ponds where adult fish would be maintained. Periodically, the fish from the pond would be harvested to determine the levels of OCls present in their tissue. If excessive levels are found based on OEHHA fish screening values, then it would be known that the OCls bioaccumulating to excessive levels downstream of the effluent discharge are potentially being derived in part from the effluent.

In setting up this approach, the pond should provide a food web similar to that which occurs in ambient waters, so that the fish could bioaccumulate OCls based not only on the OCls dissolved in the water, but also through food web accumulation. It may be possible to do this type of study with freshwater clams as the bioaccumulation test organism. As discussed below, further work needs to be done, however, to understand the relationship between the freshwater clam *Corbicula fluminea*'s degree of bioaccumulation and edible fish tissue's degree of bioaccumulation in the same waterbody.

Overall OCl Sources. Overall, it can be concluded that there is likely continuing transport of some organochlorine pesticides from areas of former use to Central Valley waterbodies. At this time, the potential significance of this source of these pesticides as a contributor to their excessive bioaccumulation is unknown. There is need for studies to determine for each listed Waterbody whether current transport of the OCls significantly contributes to the bioavailable OCl residues within the Waterbody that lead to excessive bioaccumulation in edible organism tissue.

Tissue Monitoring Data

The State Water Resources Control Board has been collecting aquatic organism tissue residue data for the organochlorine pesticides at a number of locations within the Central Valley since the late 1970s. In addition, there have been a number of special-purpose studies conducted by the USGS, the DeltaKeeper (SFEI), DWR, and the Sacramento River Watershed Program that have provided data on OCl concentrations in Central Valley aquatic life. Appendix C presents a tabulation of the existing database. Figures 1(a) through 1(k) present the maps that were provided by the various investigators showing the locations where the aquatic organism data were collected. Presented below is a summary of the general characteristics of each of the major study programs that have been conducted in the Central Valley for the determination of the OCl content of edible tissue of fish and other organisms.

SWRCB Toxic Substances Monitoring Program. Beginning in 1976, the State Water Resources Control Board (SWRCB/TSMP, 2002) initiated the Toxic Substances Monitoring Program (TSMP) of state of California fish and some other aquatic life for excessive concentrations of potentially hazardous chemicals such as the OCls. This program has provided data on the occurrence of excessive OCls in fish in California Central Valley waterbodies (see Figures 1(i)(j) and (k) for sampling locations). Unfortunately, the funding made available to this program in recent years has been inadequate compared to that needed to adequately characterize existing concentrations of OCls and other constituents of concern in fish in any particular Central Valley waterbody, much less at all of the locations that should be periodically sampled to determine if there are existing OCl bioaccumulation problems in edible fish as well as trends over time in the concentrations of the OCls of concern in edible fish.

The approach that has been followed in the TSMP is for the State Water Resources Control Board staff to allocate funds to the Regional Boards, where the Regional Board staff determines the locations and types of fish/other organisms that should be evaluated, as well as the constituents that should be analyzed and the degree of sensitivity that those doing the analysis should use in determining the tissue concentrations of OCls in the fish/aquatic life samples collected. One of the problems with the TSMP that persists still today is that the Regional Board staff responsible for specifying the analytical methods to be used have not been specifying readily available methods that could detect certain of the OCls, such as dieldrin, at the OEHHA human health fish screening levels. As it stands now, data have been and continue to be generated in this program where the concentrations are reported as less than the detection limit used, yet the detection limit is above the OEHHA screening level.

David Crane, who heads the Department of Fish and Game analytical laboratory that does the TSMP analyses, indicated that he has previously informed the Regional Board staff that he can do the analyses with a lower detection limit; however, the cost for analysis increases. Based on discussions with the Regional Board staff of several Regional Boards, it was learned that they are not aware of this situation. This has resulted in the TSMP continuing to generate data that is of limited value for several potentially significant parameters, because of the inadequate detection limits used in the analysis of the fish tissue. This situation should be changed so that all analyses are conducted with an analytical detection limit that is at least slightly below the OEHHA human health fish screening value, considering waterbody-specific fish consumption rates.

Previously, the TSMP developed periodic reports on the results of the monitoring. No new reports have been issued since 1997. Some of the data collected since then have been posted to the State Water Board website, http://www.swrcb.ca.gov/programs/smw/

index.html. However, there are additional TSMP data that the Regional Boards have obtained on concentrations of OCls in fish that are not available from the State Board website.

According to C. Foe (pers. comm., 2002), the TSMP collected fish from several locations in the Sacramento River watershed in 2001. At the time of preparation of this report, the data from the analysis of these fish are not available. These data should be added to the database presented in Appendix C, and discussed relative to information the data provide on exceedances of OEHHA screening values in edible fish tissue.

Sacramento River Watershed Program. In the mid-1990s, participants in the Monitoring subcommittee of the Sacramento River Watershed Program determined that the initial monitoring program should be focused on the use of an Evaluation Monitoring approach, which would be designed to detect potential water quality problems (beneficial use impairments) in the Sacramento River and its major tributaries (see Figure 1(a) for sampling locations). As discussed by Jones-Lee and Lee (1998), Evaluation Monitoring focuses on determining the impacts of chemicals, as opposed to their concentrations. With respect to evaluating a potential bioaccumulation problem, rather than measuring the concentrations of OCls in water and then trying to extrapolate from worst-case CTR criteria to excessive bioaccumulation in edible fish tissue, edible fish are collected and the edible tissues are analyzed for constituents of potential concern. This is a reliable approach for evaluating whether there is an excessive bioaccumulation problem in a waterbody.

Two of the main thrusts of the Sacramento River Watershed Program monitoring efforts were devoted to assessing aquatic life toxicity and excessive bioaccumulation of potentially hazardous chemicals in edible fish within the mainstem of the Sacramento River and its major tributaries. Since there was limited information on the presence of organochlorine pesticides and PCBs in Sacramento River fish, SRWP funds were devoted to collecting fish from selected locations in the Sacramento River and analyzing them for the organochlorine pesticides and PCBs. In September and October of 1997-2000, the SRWP collected fish from 17 locations and analyzed these for a suite of the legacy organochlorine pesticides and PCBs. The most recent SRWP annual report (LWA, 2002) presents all of the data that have been collected in this monitoring program. The final qualified data have been made available on the SRWP website (http://www.sacriver.org/subcommittees/monitoring/documents/SRWP_AMR_00-01_FINAL.pdf). The SRWP fish tissue OCl monitoring program has revealed a hitherto unrecognized problem of excessive concentrations of several organochlorine pesticides (DDT, dieldrin, chlordane) and PCBs in Sacramento River edible fish. The SRWP data are presented in Appendix C. The Sacramento River now is one of the more comprehensively recently-monitored waterbodies in the Central Valley with respect to OCl content of edible fish tissue.

Based on the information available, the Sacramento River or parts thereof should be considered for listing as a 303(d) "impaired" waterbody with respect to excessive bioaccumulation of DDT, chlordane, dieldrin, and PCBs in certain edible fish. At this time, studies have not been done to define the sources of the OCls that are leading to excessive OCl tissue residues in edible fish in the Sacramento River and its tributaries.

A set of data of Sacramento River watershed fish was collected in the fall of 2001. At this time, these data have not yet been made available for inclusion in this report. These data should be added to the database presented in Appendix C, and discussed relative to information the data provide on exceedances of OEHHA screening values in edible fish tissue.

DeltaKeeper Studies. William Jennings (the DeltaKeeper), through litigation settlement with the Port of Stockton, devoted settlement funds to conducting a monitoring program of tissue residues of fish taken from the Delta and its major tributaries. Additional support for this program was derived from the Central Valley Regional Water Quality Control Board. The study was conducted by the San Francisco Estuary Institute (SFEI), with Jay Davis as the lead scientist (Davis, *et al.*, 2000). The planning and reporting of the data collected in this 1998 study was a joint effort between Dr. Chris Foe of the CVRWQCB, William Jennings (the DeltaKeeper) and Jay Davis of SFEI. This study provided data on the concentrations of OCls in Delta and Delta tributary fish. The data from the DeltaKeeper/SFEI study have been incorporated into the database presented in Appendix C.

This study, in addition to determining the concentrations of OCls at several traditional TSMP monitoring stations, also included collecting samples at locations where there had been no previous TSMP monitoring, such as in the Smith Canal in the city of Stockton. It was the monitoring of the Smith Canal fish that showed that largemouth bass and white catfish taken from the Canal had high concentrations of PCBs compared to other locations where OCl monitoring had been done in the Delta and its tributaries. Additional fish samples have been taken in Smith Canal and a number of other locations that have not been analyzed because of a lack of funding. They are stored frozen and should be analyzed as soon as funds become available.

SFEI (2001, 2002) has provided summary information on the studies that have been conducted on OCl content of Delta fish. Their website, www.sfei.org, can be consulted for background information on previous work.

USGS NAWQA. Data on OCl concentrations in edible fish tissue and in other organisms, such as clams and crayfish, from Central Valley waterbodies have been developed by the US Geological Survey as part of their NAWQA program. The USGS NAWQA program has also developed water column and sediment data on the concentrations of OCls at several locations within the Central Valley (see Figures 1(b) through 1(h) for sampling locations). These data have been incorporated into the database developed in this project, which is presented in Appendix C. The USGS NAWQA program also includes studies on current sources of OCls in agricultural runoff from San Joaquin River westside tributary streams in the Central Valley. The USGS has issued a series of publications covering the NAWQA studies. Those that are pertinent to this OCl excessive bioaccumulation TMDL are listed in this report's Reference list. The reports by Brown

(1998), Domagalski (1997, 2000), Domagalski and Dileanis (2000), Domagalski, *et al*. (2000), Kratzer (1998a,b, 1999), MacCoy and Domagalski (1999), Panshin, *et al*. (1998), and USGS (1995a,b) are the reports of greatest relevance to this review.

Department of Water Resources (DWR). The Department of Water Resources, under the leadership of J. Boles, has conducted some OCl fish tissue analysis as part of its upper Sacramento River tributary monitoring program (see Figure 1(a) for sampling locations). The data have been reported by LWA (2002). Those data have been incorporated into this report in Appendix C. Fish were monitored for organochlorine pesticides and PCBs in 1999 from Deer Creek, Mill Creek, Big Chico Creek, and Clear Creek watersheds.

Data Compilation

All available data have been converted to a standard Excel spreadsheet, which is presented in Appendix C. The data presented in this spreadsheet is color-coded yellow to indicate exceedances of OEHHA (Table 4) standard fish consumption rate human health screening values. Also, highlighted in green are those data entries that are just below the OEHHA screening values. Highlighted in blue are the data where the detection limit for the measurement was above the OEHHA screening value. The Table 4 screening values are based on an average consumption rate of 21 g/day and an upper-bound cancer risk of 1×10^{-5}. As discussed herein, this consumption rate may be low compared to consumption of fish by some individuals for certain of the listed Waterbodies. Further, a factor of 10 lower allowable edible tissue residues would be appropriate if an upper bound cancer risk of 1 in a million is used.

The focus of the discussions provided in this section is on the more recent data (1997-2000), with respect to whether there are exceedances of the OEHHA screening values. In the discussion presented below, failure to mention a particular analyzed pesticide or PCB at a particular location or date indicates that exceedances of screening values did not occur or were not measured.

The monitoring program of OCls in Central Valley fish has varied significantly over the years. Frequently, five to six fish were taken at a particular location, where the composite of the fish was analyzed. Some of the monitoring programs, however, only took one to two fish at a location and time. Some of the investigations included an analysis of only some of the OCls. There have been frequent problems with investigators using analytical methods with inadequate detection limits to detect all of the OCls at OEHHA screening values. Further, only some of the investigators determined the percent lipid of the fish samples. The complete record of the information available is included in Appendix C.

Where appropriate, plots of the data for each location and each OCl where exceedances of the screening value were found, are presented. The plots distinguish between the types of fish and other organisms through color-coding and symbol. The OEHHA standard fish screening values are indicated on each plot. Where the data are reported as less than the detection limit, the data are plotted as the detection limit with a down arrow, indicating that they are less than the detection limit.

Examination of the plots presented in the following sections shows several general characteristics. During the late 1970s through the late 1980s, for about 10 years, the TSMP collected substantial OCl data on certain types of fish and other organisms from Central Valley waterbodies. Except for an occasional value in late 1990, there were little or no data collected from 1989 through 1998, when the DeltaKeeper/SFEI study was conducted. There were also some fish OCl data collected in 2000.

While white catfish were collected by the TSMP in the 1980s and in 1998, largemouth bass were not collected in the TMSP studies of the 1980s. The TSMP collected channel catfish during the 1980s. There are, however, no channel catfish data collected since 1990. This situation makes discerning of trends in important game fish (largemouth bass) impossible. As discussed by Davis, *et al*. (2000), there is, however, an apparent decrease in the tissue concentrations of various OCls in the white catfish collected in the late 1970s through the mid-1980s, compared to more recently collected fish.

Consideration was given to further statistical analysis of the data. However, sufficient data for appropriately comparable fish type, age and size, using sufficiently sensitive analytical methods for OCl measurement do not exist to warrant further data review.

Figure 1 presents maps of all the sampling locations where OCl data have been collected in the Central Valley. The discussion of the data presented in the following sections focuses on each of the watersheds, starting at the top of the watershed and proceeding toward the Delta. Within the Delta, the discussion focuses on the San Joaquin River and the Deep Water Ship Channel, then focusing on the eastern Delta, central Delta and southern Delta.

San Joaquin River Watershed

San Joaquin River at Highway 99. In 2000, the TSMP collected largemouth bass from where the San Joaquin River crosses Highway 99. All of the measured OCls were below OEHHA screening values.

San Joaquin River at Lander Avenue and at Crow's Landing. DeltaKeeper/SFEI collected fish from the San Joaquin River at Lander Avenue and at Crow's Landing in 1998. In 1998, white catfish and largemouth bass were sampled from the San Joaquin River at Lander Avenue. White catfish had an exceedance of dieldrin above the OEHHA screening value, while dieldrin in the largemouth bass did not have sufficiently sensitive analytical methods to determine if there were exceedances above the OEHHA screening values. Largemouth bass collected at both of these locations did not contain excessive tissue residues of any of the measured OCls. The TSMP collected largemouth bass in 2000 from these locations and also did not find exceedances of OCls in this area. It appears that the current source of the OCls for the mid- and lower part of the San Joaquin River occurs below Crow's Landing.

Mud and Salt Sloughs. In 1980 the TSMP found that Mud Slough white catfish contained concentrations of toxaphene above OEHHA screening values. Black Crappie taken from Mud Slough in 1987 did not contain any of the OCls above the OEHHA screening value. In 1992, the USGS collected carp from Mud Slough near Gustine. The tissue sampled of this carp contained concentrations of total DDT below the OEHHA screening value. The detection limits used by the USGS for dieldrin, chlordane, toxaphene and total PCBs were inadequate to detect these chemicals at the screening value. The TSMP collected white catfish from Mud Slough in 1998. The concentrations of total DDT, dieldrin, toxaphene and total PCBs were above OEHHA screening values.

During the 1980s several kinds of fish taken from Salt Slough by the TSMP contained excessive concentrations of total DDT and toxaphene. The USGS, in 1992, sampled channel catfish from Salt Slough near Stevinson. The tissue concentrations of total DDT and dieldrin were above OEHHA screening values. The analytical methods used for chlordane, toxaphene and PCBs were not adequate to determine if there were fish tissue exceedances of the OEHHA screening value.

Merced River. The Merced River fish taken from 1978 through 1983 by the TSMP contained excessive concentrations of total DDT and dieldrin. The USGS sampled Asiatic clam in 1992. The concentrations of total DDT were above the OEHHA screening value. The detection limits used for dieldrin, chlordane, toxaphene, and total PCBs were inadequate to detect these chemicals at the screening value. The TSMP collected channel catfish and largemouth bass from the Merced River at the Hatfield St. Recreation Area in 1998. These fish contained excessive concentrations of total DDT, dieldrin, toxaphene, and total PCBs above the OEHHA screening values. All recent Merced River fish tissue values for total chlordane are below the OEHHA screening value.

Also, the DeltaKeeper/SFEI collected largemouth bass from the Merced River upstream of Hatfield St. Recreation Area in 1998. OCls were not found above OEHHA screening values in this sample of fish. It is not clear, however, whether these two sets of fish (collected at the Hatfield St. Recreation Area and "upstream" of the Hatfield St. Recreation Area) can be considered as having been collected from the same waterbody, or represent areas where there is OCl pesticide input between the two locations.

San Joaquin River Westside Tributaries. The USGS NAWQA early to mid-1990 studies found that the westside tributaries, Orestimba Creek, Spanish Grant Drain, Olive Avenue Drain, Del Puerto Creek, Ingram Creek and Hospital Creek, are all contributing certain OCls at measurable concentrations to the San Joaquin River. In 1992, the USGS sampled the Asiatic clam *Corbicula fluminea* from Orestimba Creek, Spanish Grant Drain and Del Puerto Creek. Clams from all three locations contained excessive DDT compared to OEHHA screening values. The concentrations of dieldrin and toxaphene were also above the OEHHA screening values from Orestimba Creek. Inadequate sensitivity was used on chlordane and PCBs sampled in Orestimba Creek. Inadequate detection limits were used for dieldrin, chlordane, toxaphene, and PCBs in Del Puerto Creek. The analyses of fish taken from Spanish Grant Drain used inadequate methods for dieldrin and chlordane, but had exceedances of toxaphene and PCBs. There has been no recent sampling of aquatic organisms in any of these westside tributaries. Because of the high concentrations found in the early 1990s, this is an area that should have a high priority for OCl fish tissue studies.

Turlock Irrigation District, Lateral #5. The USGS sampled crayfish in 1992 from the Turlock Irrigation District, Lateral #5. The concentrations of total DDT were below the OEHHA screening value. The detection limits used for dieldrin, chlordane, toxaphene, and total PCBs were inadequate to detect these chemicals at the screening value.

Lower Tuolumne River. The Tuolumne River near where it enters the San Joaquin River is one of the 303(d) listed Waterbodies for excessive OCl bioaccumulation. Examination of the data that have been collected from 1978 through 1998 shows that, for total DDT (Figure 4), there were fish taken from the 1980s and 1998 that had tissue residues above the OEHHA screening value. The same situation applies to dieldrin (Figure 5). The total chlordane content (Figure 6) of fish taken from this location in 1998 was less than the OEHHA screening value. The concentrations of toxaphene (Figure 7) in fish taken from the Lower Tuolumne River in 1998 were, for largemouth bass, above the screening value. Total PCBs (Figure 8) in largemouth bass taken from this location in 1998 were also above the screening value. Again, as with other data sets, the facts that the largemouth bass were the only fish sampled in 1998 from the Lower Tuolumne River, no largemouth bass were collected earlier and no channel catfish were collected at this location in the more recent data, makes discerning trends impossible.

In 1992, the USGS sampled Asiatic clam from the Tuolumne River at Modesto. The concentrations of total DDT were below the OEHHA screening value. The detection limits used for dieldrin, chlordane, toxaphene and total PCBs were inadequate to detect these chemicals at the screening value.

Another issue of concern is whether the fish taken from the Lower Tuolumne River represent fish that have acquired their OCl residues from upstream Tuolumne River sources or could be fish that have moved into the Tuolumne River from the San Joaquin River, where they acquired the OCl residues from the San Joaquin River. It is not possible to make this distinction with the information available at this time.

Dry Creek in Modesto, a tributary of the Tuolumne River, was sampled in 1992 by the USGS, for Asiatic clam. The concentrations of total DDT were below the OEHHA screening value. The detection limits used for dieldrin, chlordane, toxaphene and total PCBs were inadequate to detect these chemicals at the screening value.

Stanislaus River. Various kinds of fish sampled by the TSMP in the Stanislaus River in 1978 through the early 1980s contained excessive concentrations of total DDT, dieldrin, toxaphene and total PCBs. In 1992, the USGS sampled Asiatic clam from the Stanislaus River near Ripon. The concentrations of total DDT were below the OEHHA screening value. The detection limits used for dieldrin, chlordane, toxaphene, and total PCBs were inadequate to detect these chemicals at the screening value. In 2000, largemouth bass

Figure 4

Concentrations of Total DDT in Aquatic Organisms
Tuolumne River at San Joaquin River 1978 - 2000

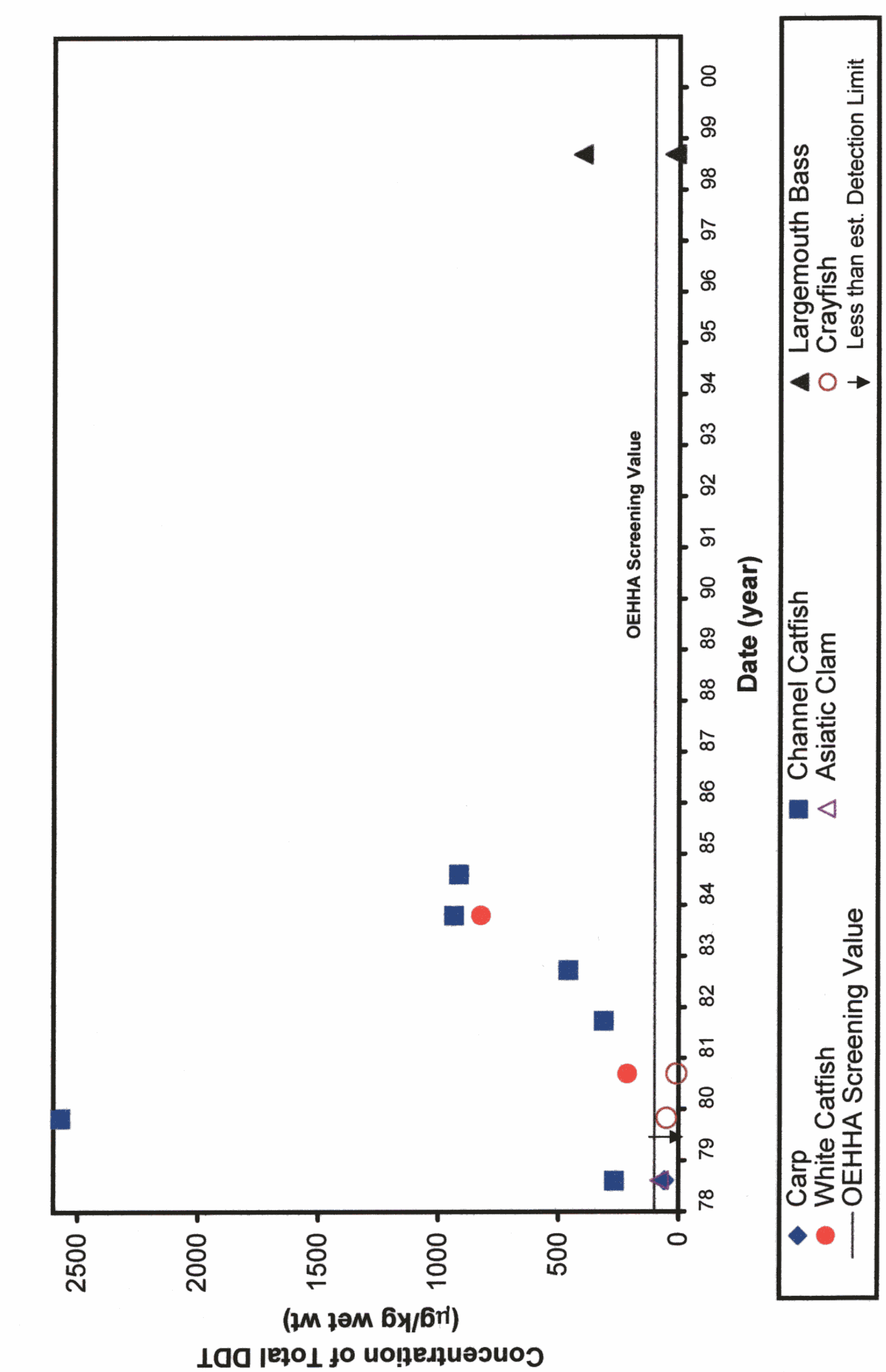


Figure 5

Concentrations of Dieldrin in Aquatic Organisms
Tuolumne River at San Joaquin River 1978 - 2000

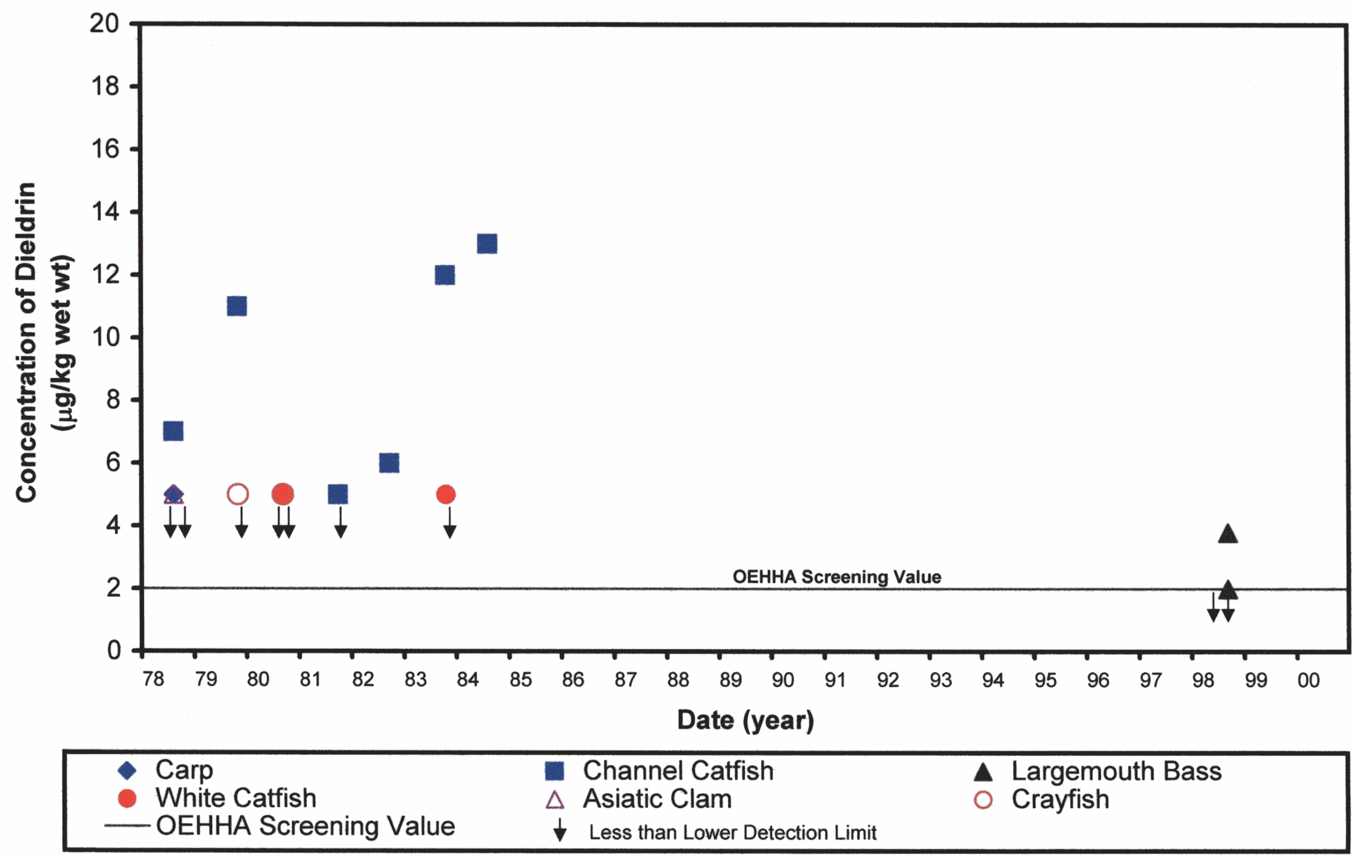
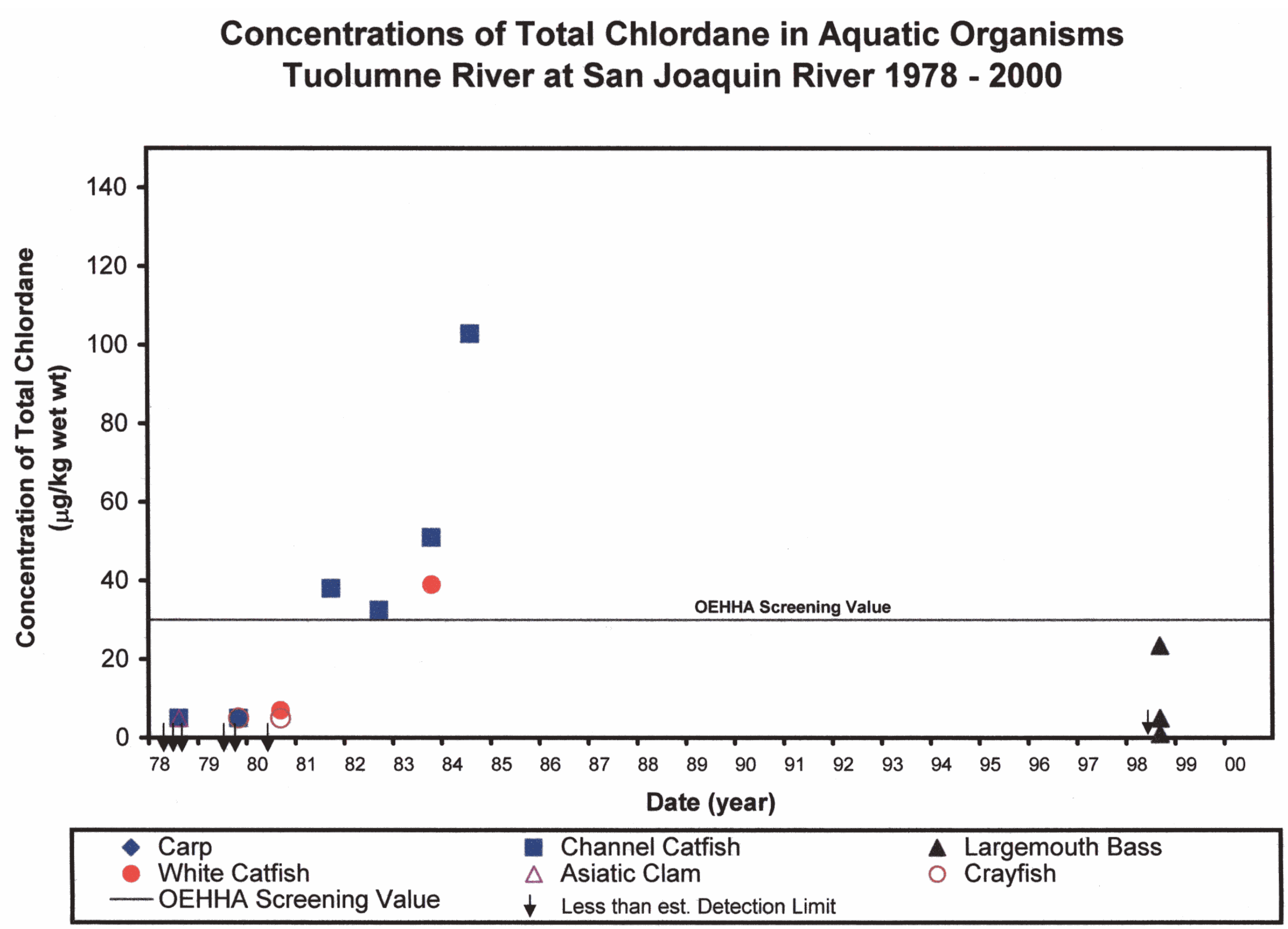


Figure 6



Concentrations of Total Chlordane in Aquatic Organisms
Tuolumne River at San Joaquin River 1978 - 2000
Concentration of Total Chlordane (µg/kg wet wt)
0
20
40
60
80
100
120
140
OEHHA Screening Value
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00
Date (year)
Carp
White Catfish
OEHHA Screening Value
Channel Catfish
Asiatic Clam
Less than est. Detection Limit
Largemouth Bass
Crayfish

Figure 7

Concentrations of Toxaphene in Aquatic Organisms
Tuolumne River at San Joaquin River 1978 - 2000

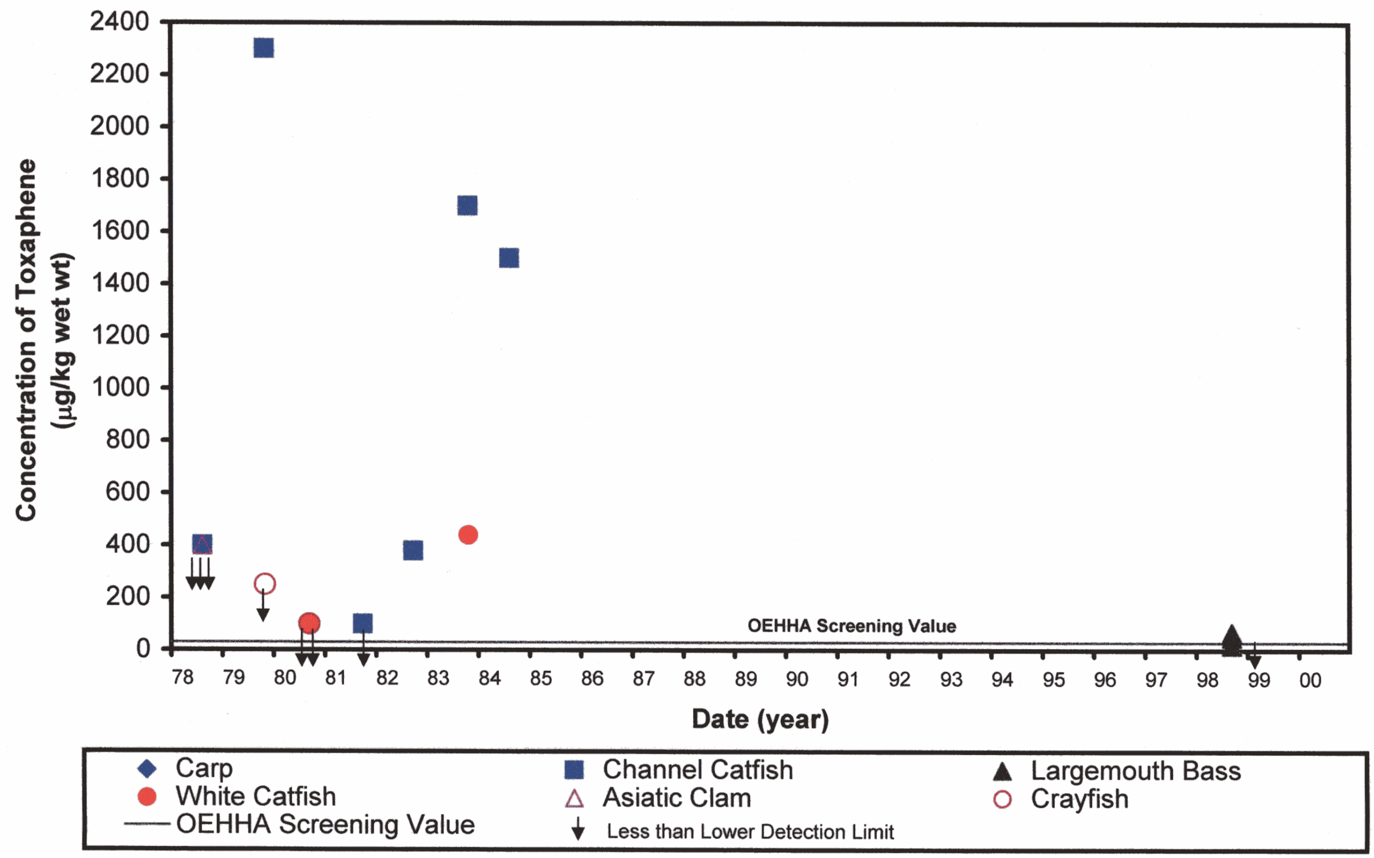
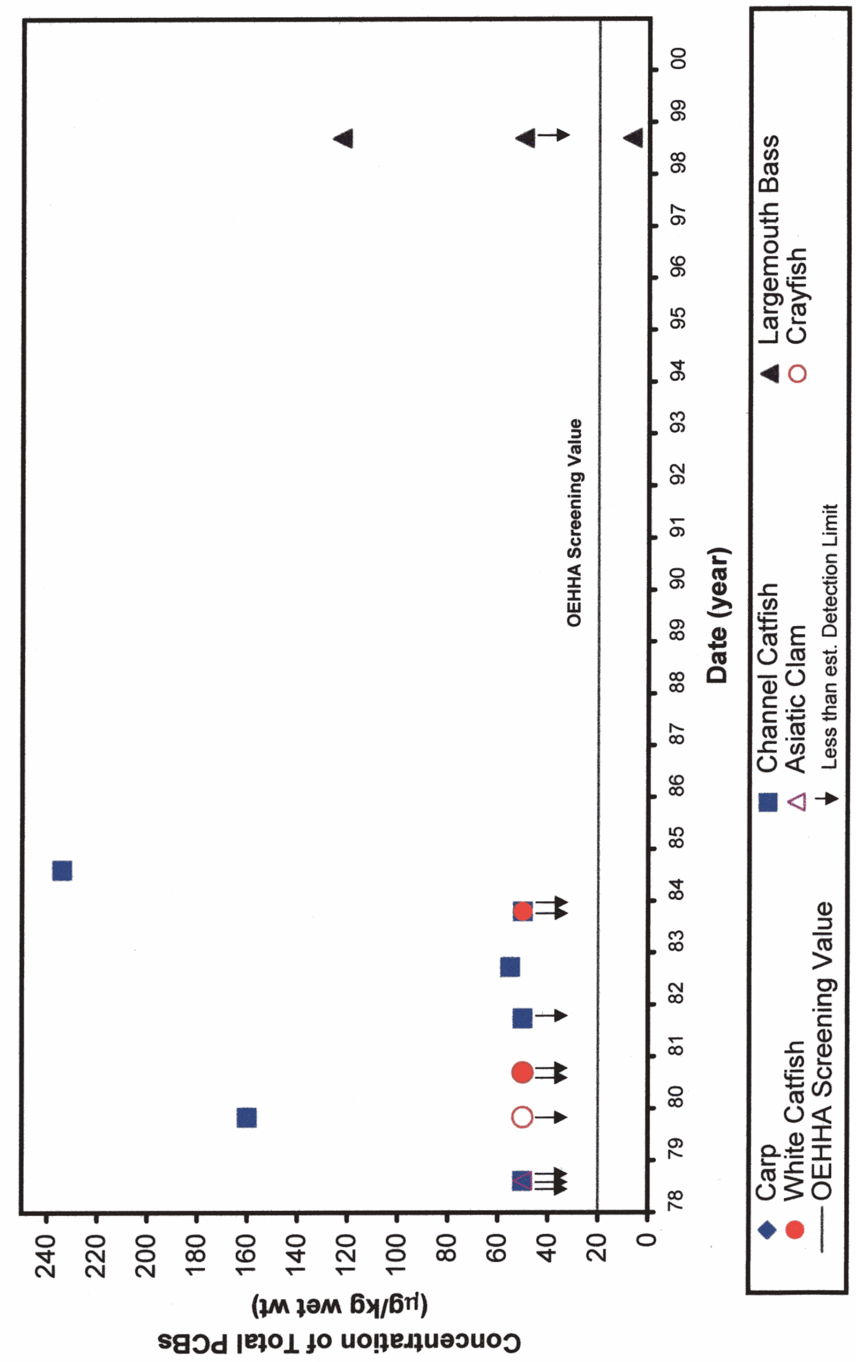


Figure 8

Concentrations of Total PCBs in Aquatic Organisms
Tuolumne River at San Joaquin River 1978 - 2000



were sampled by the TSMP and found to not have exceedances of total DDT. The measurements of all other OCls were done with insufficient sensitivity to determine if there were exceedances above the OEHHA screening value. DeltaKeeper/SFEI, in 1998, collected largemouth bass from the Stanislaus River upstream from Caswell Park. Total DDT and total PCBs exceeded OEHHA screening values.

San Joaquin River at/near Vernalis. One of the major data sets for OCl fish tissue residues is for several types of fish taken from the San Joaquin River at or near Vernalis. Figure 9 presents the concentration of total DDT found in fish and other organism tissue taken from the San Joaquin River at or near Vernalis from 1978 through 2000. In the 1980s, there were large numbers of fish taken from this location which had total DDT well above the OEHHA screening value. The data obtained in 1998 and 2000 show that a sample of largemouth bass and white catfish had total DDT at this location above the OEHHA screening value.

Figure 10 presents a plot of the dieldrin data obtained in aquatic organisms from the San Joaquin River at Vernalis for 1978 through 2000. Many of the fish analyzed as part of the TSMP did not involve the use of sufficiently sensitive analytical methods to determine if the dieldrin concentrations were above the OEHHA screening value. The concentrations of dieldrin present in the San Joaquin River at Vernalis in white catfish and largemouth bass in 1998 and 2000 were at or above the OEHHA screening value.

The total chlordane concentrations in San Joaquin River fish taken from Vernalis during the 1980s (see Figure 11) frequently exceeded the OEHHA screening value. However, examination of Figure 11 shows that only one of the three sets of fish samples taken in 1998 and 2000 was at the OEHHA screening value for total chlordane. All of the others were below the OEHHA screening value.

The 1980s' TSMP data show that toxaphene was present in San Joaquin River fish at Vernalis well above the OEHHA screening value. While, as shown in Figure 12, white catfish data from this location show a decrease in toxaphene concentrations, there are concentrations of toxaphene in largemouth bass from this location considerably above the OEHHA screening value. Figure 13 shows that, during the 1980s, some channel catfish had very high tissue residues of toxaphene. There have been no recent channel catfish data to determine if this situation persists today.

The total PCB content of fish and other organisms taken from the San Joaquin River at Vernalis during the 1980s was well above the OEHHA screening value. The more recent data (see Figure 14) show that PCB tissue residues of white catfish and largemouth bass taken at this location in 1998 were above the OEHHA screening value. There is need for channel catfish data from the San Joaquin River at Vernalis to determine if the elevated concentrations found in the 1980s persist today in this type of fish and whether there has been a downward trend in these concentrations.

Figure 9

Concentrations of Total DDT in Aquatic Organisms
San Joaquin River at Vernalis 1978 - 2000

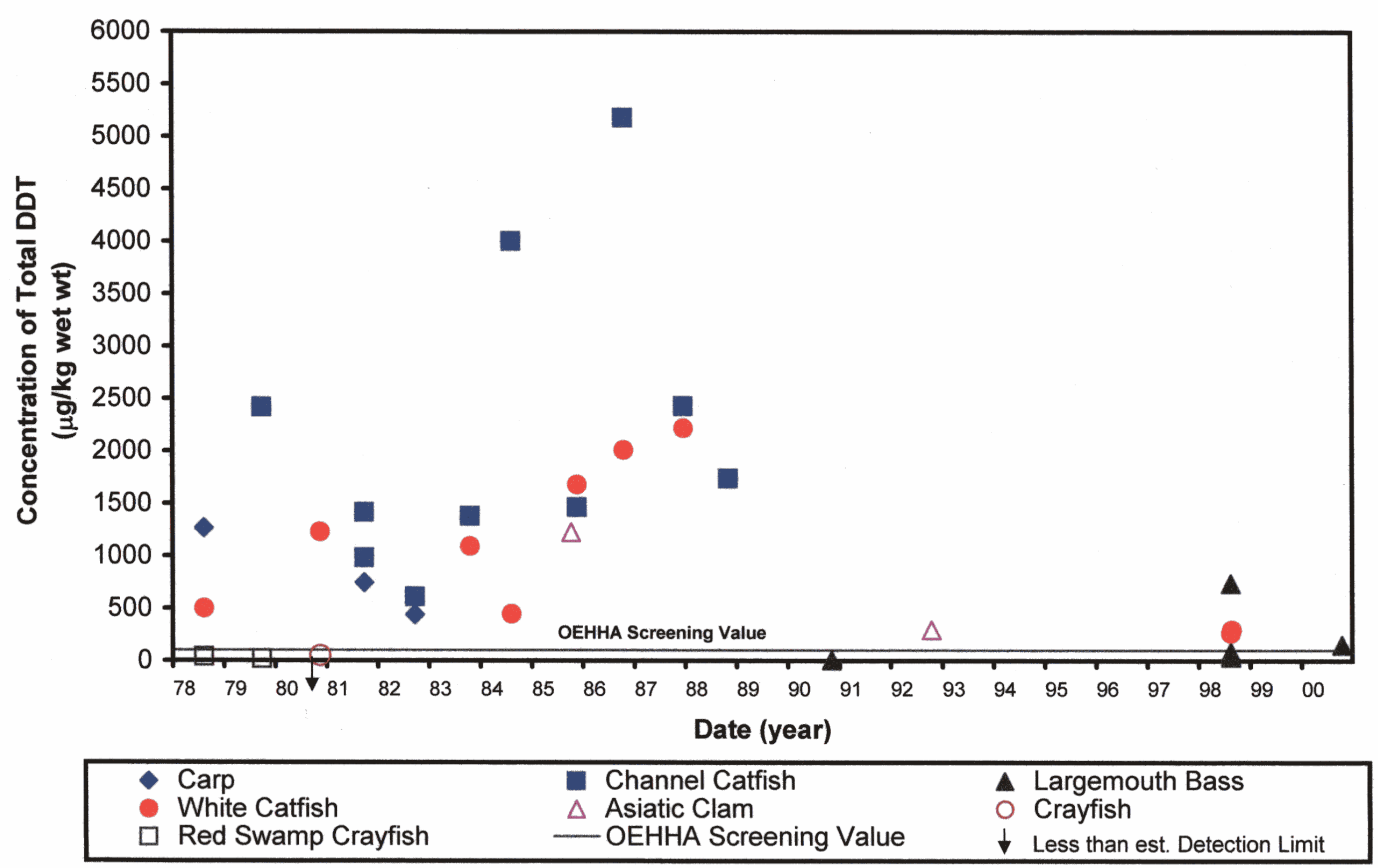


Figure 10

Concentrations of Dieldrin in Aquatic Organisms
San Joaquin River at Vernalis 1978 - 2000

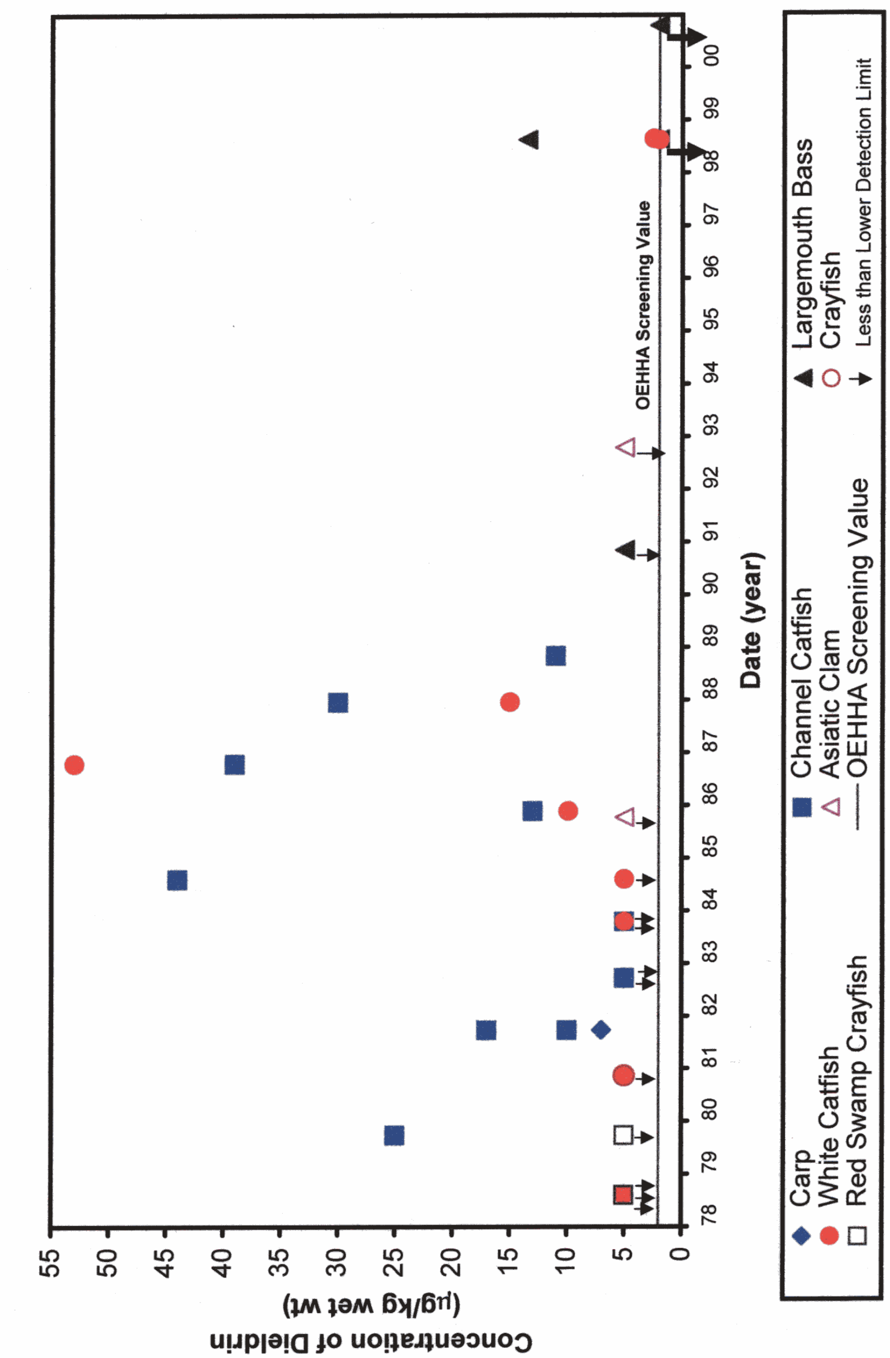
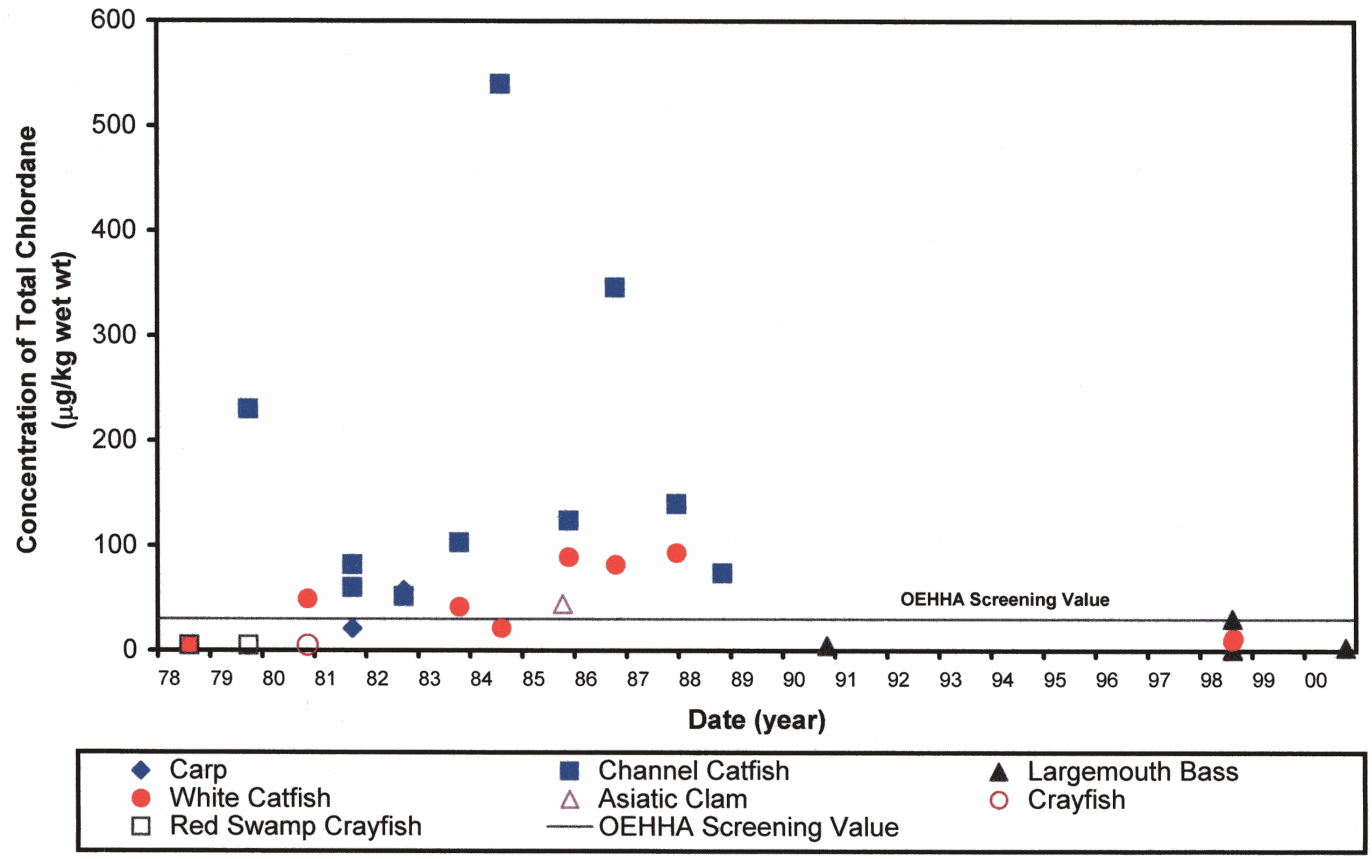


Figure 11

Concentrations of Total Chlordane in Aquatic Organisms
San Joaquin River at Vernalis 1978 - 2000

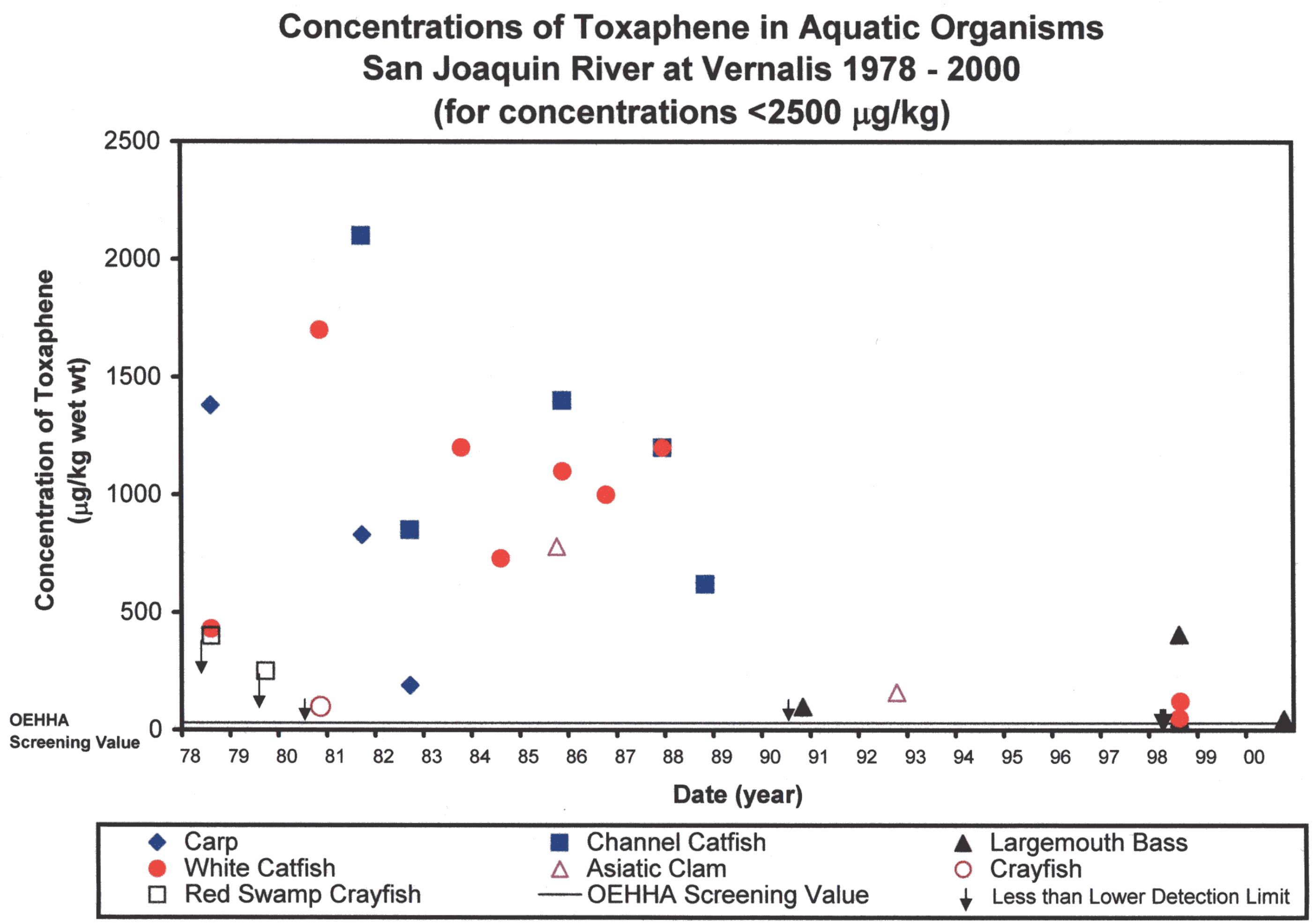


Examination of the 1992 fish tissue data collected by the USGS from the San Joaquin River upstream of Vernalis near Stevinson and Patterson showed concentrations of total DDT in bluegill and carp above the OEHHA screening value. The detection limits for dieldrin used by the USGS were inadequate to determine if the dieldrin content in fish obtained at these two locations in 1992 were above the OEHHA screening value. Bluegill and carp taken from these locations in 1992 contained excessive toxaphene and total PCBs. An Asiatic clam was also taken at Vernalis by the USGS in 1992. Exceedances of DDT and toxaphene were found in the clam. Inadequate detection limits to determine if there were exceedances of the OEHHA screening values were used for dieldrin and chlordane. It is therefore concluded that, for many of the OCls that are causing 303(d) listings, the problem of excessive bioaccumulation appears to persist in fish taken from various locations in the San Joaquin River. This is to be expected, since the primary source of the OCls that are bioaccumulating to excessive levels in fish taken at Vernalis is upstream of Vernalis, from agricultural and/or urban areas.

San Joaquin River near Mossdale. Largemouth bass were sampled in the San Joaquin River near Mossdale in 1992 and 1993. Total DDT was found in these fish for both years above the OEHHA screening value. This location was not sampled in the more recent fish collection from the San Joaquin River in this region. Sufficiently sensitive analytical methods were not used to determine if dieldrin, chlordane, toxaphene, and PCBs were present in these fish above the OEHHA screening values.

San Joaquin River at Bowman Road and Highway 4. In 1998, the DeltaKeeper/SFEI collected largemouth bass and white catfish from the San Joaquin River "around Bowman Road" and "north of Highway 4." These locations are upstream of the San Joaquin River Deep Water Ship Channel. The largemouth bass did not show

Figure 12



Concentrations of Toxaphene in Aquatic Organisms
San Joaquin River at Vernalis 1978 - 2000
(for concentrations <2500 µg/kg)
Concentration of Toxaphene (µg/kg wet wt)
2500
2000
1500
1000
500
0
OEHHA Screening Value
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00
Date (year)
Carp
White Catfish
Red Swamp Crayfish
Channel Catfish
Asiatic Clam
OEHHA Screening Value
Largemouth Bass
Crayfish
Less than Lower Detection Limit

Figure 13

Concentrations of Toxaphene in Aquatic Organisms San Joaquin River at Vernalis 1978 - 2000 (all data)

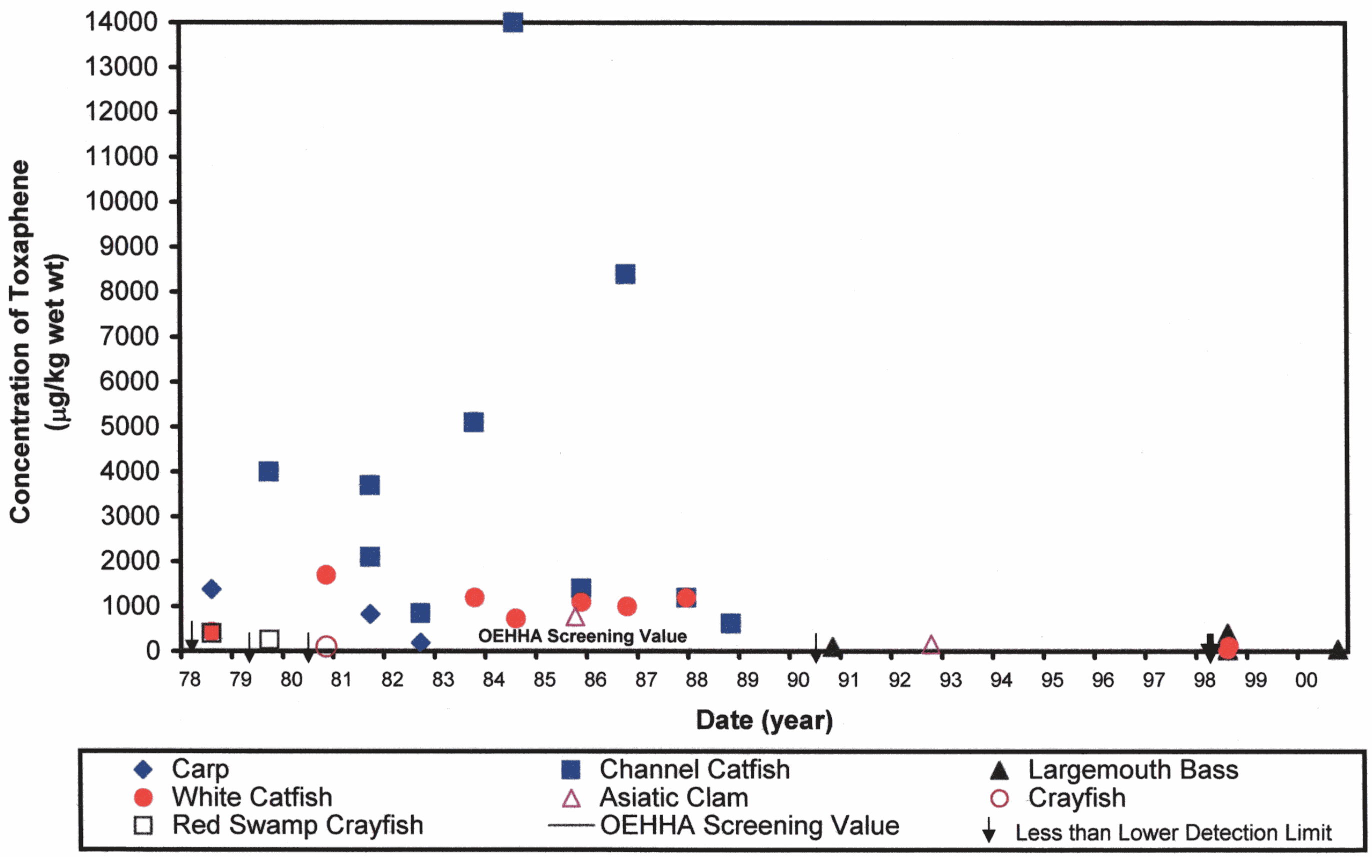
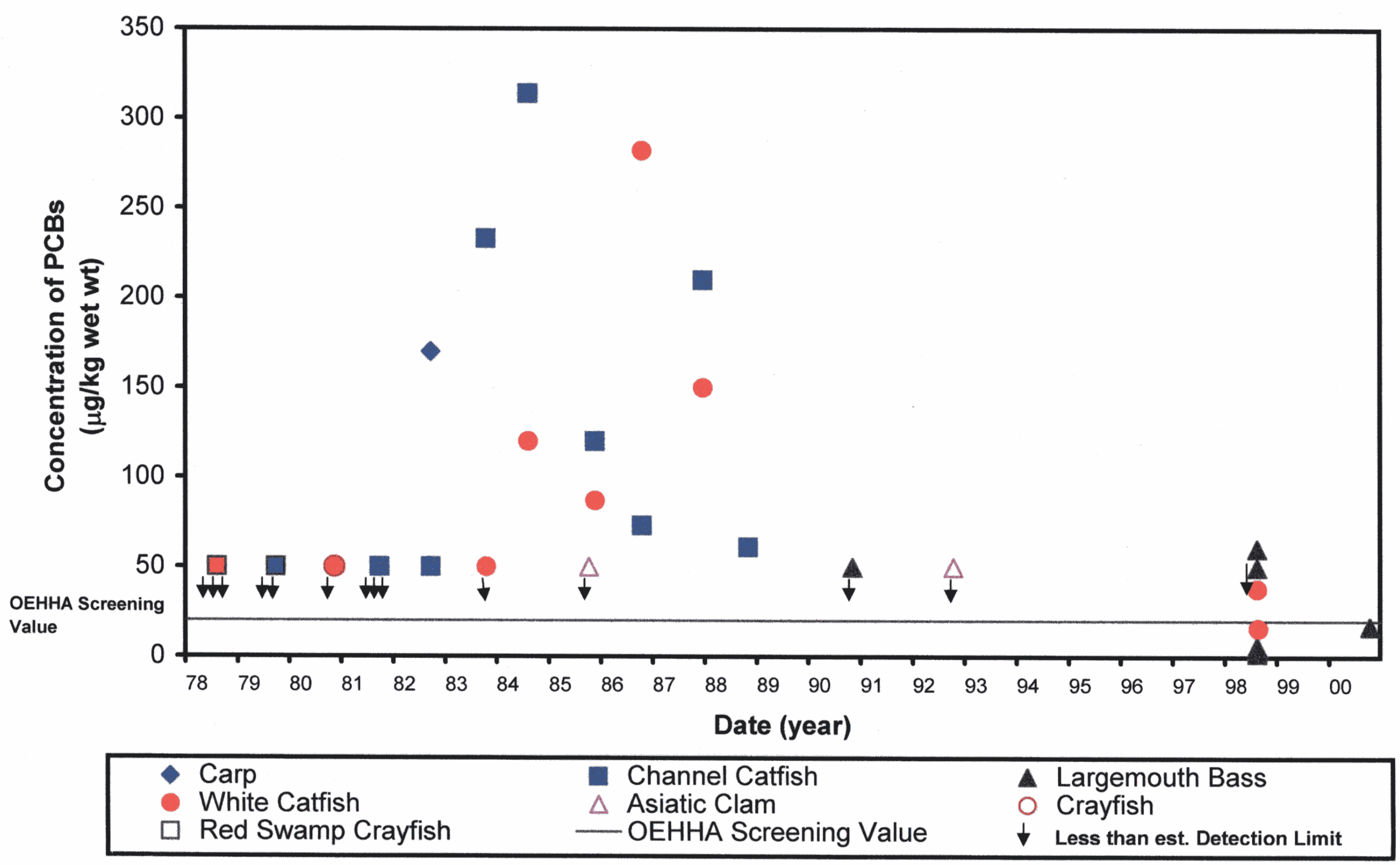


Figure 14

Concentrations of Total PCBs in Aquatic Organisms
San Joaquin River at Vernalis 1978 - 2000



exceedances of any of the measured OCls above the OEHHA screening values. White catfish taken from the San Joaquin River near Bowman Road and Highway 4 at the same time had total DDT above the OEHHA screening value. White catfish taken from the San Joaquin River at Bowman Road had total PCBs above the OEHHA screening value, while its chlordane concentration was below the OEHHA screening value. White catfish taken from the San Joaquin River near Highway 4 had total chlordane and PCBs less than the OEHHA screening value. The detection limits used for dieldrin and toxaphene were above the OEHHA screening values. There was no earlier sampling of fish at these locations.

Sacramento River Watershed

Sacramento River at Keswick. The fish in the Sacramento River at Keswick have been sampled periodically since the early 1980s. In 1987, rainbow trout tissue did not have exceedances of OEHHA values. However, sucker fish tissue had concentrations of PCBs above OEHHA screening values. In 1997, rainbow trout taken from the Sacramento River below Keswick did not have excessive DDT. However, there was an exceedance of PCBs above the OEHHA screening value. Toxaphene was not measured. Chlordane was found to be below the OEHHA screening value. Dieldrin was not measured with sufficiently sensitive analytical methods to determine if there were exceedances above the OEHHA screening values. In 1998, again rainbow trout were sampled. Dieldrin and chlordane were not measured with sufficiently sensitive analytical methods to determine if there were exceedances above the OEHHA screening values. DDT and PCBs were below the OEHHA screening values. Again, toxaphene was not measured. Rainbow trout were analyzed in 2000 and found to have no exceedances compared to the OEHHA screening values for DDT and PCBs. Dieldrin and chlordane were not measured with sufficiently sensitive analytical methods to determine if there were exceedances above the OEHHA screening values. Toxaphene was not measured.

Sacramento River at Bend Bridge near Hamilton City. Fish taken from the Sacramento River above Bend Bridge, near Hamilton City, were sampled in 1998 and 2000. None of the fish had concentrations of the OCls of interest above the OEHHA screening value.

Sacramento River Upstream Tributaries. There have been a number of measurements of the OCl concentrations in edible fish tissue taken from various Sacramento River upstream tributaries and upstream of Lake Shasta. The DWR data, collected in 1999 and 2000 from Deer Creek, Mill Creek, Big Chico Creek and Clear Creek watersheds, did not show exceedances of any of the measured OCls in edible fish tissue. Fish were sampled at McCloud River, taken at the McCloud River Bridge, during the late 1970s and early 1980s. None of the fish sampled had excessive OCls. The USGS sampled ruffle sculpin from the McCloud River below Ladybug Creek near McCloud in 1995. Inadequate detection limits for total DDT, dieldrin, chlordane, toxaphene, and PCBs were used. The USGS sampled ruffle sculpin from Deer Creek near Vina, California, in 1995. Total DDT was less than the OEHHA screening value. All the other OCls and PCBs were measured using inadequate detection limits to determine if they were above the OEHHA screening values. Sacramento sucker were sampled from Cottonwood Creek in 1995. Inadequate detection limits were used for total DDT, dieldrin, chlordane, toxaphene and total PCBs to determine if there were exceedances of the OEHHA screening values. Sacramento sucker were sampled from Stony Creek below Black Butte Dam near Orland by the USGS in 1995. They found the total DDT concentration to be below the OEHHA screening value. Inadequate detection limits were used for dieldrin, chlordane, toxaphene, and total PCBs to determine if there were exceedances of the OEHHA screening values.

Sacramento River National Refuges. In 1988, the USGS sampled fish taken from Colusa National Wildlife Refuge – Powell Slough near Tract 9, Sacramento National Wildlife Refuge – North Fork Logan Creek at Norman Road crossing, Delevan National Wildlife Refuge – Stone Corral Creek at southeast corner of Tract 36, Delevan National Wildlife Refuge – Canal east of Tract 19, Colusa National Wildlife Refuge – Small Canal near Tract 16, and Sutter National Wildlife Refuge – Canal east of Tract 17. Black bullhead was sampled at the Colusa National Wildlife Refuge near Tract 9, while carp was sampled at the other locations. Excessive total DDT was found at the Sacramento National Wildlife Refuge – North Fork Logan Creek at Norman Road crossing, the Delevan National Wildlife Refuge – Stone Corral Creek at southeast corner of Tract 36, and the Colusa National Wildlife Refuge – Small Canal near Tract 16. Also, dieldrin was found at excessive levels at the Sacramento National Wildlife Refuge – North Fork Logan Creek at Norman Road crossing. All other OCls were below OEHHA screening values. There have been no recent data collected from fish or other aquatic life in these refuges.

Sacramento River at Colusa. In 1995, the USGS sampled Asiatic clam from the Sacramento River at Colusa and found that the total DDT was below the OEHHA screening value. Inadequate detection limits were used for dieldrin, chlordane, toxaphene and total PCBs to determine if there were exceedances of the OEHHA screening values. The Sacramento River Watershed Program found that there were no exceedances in 1998 in the Sacramento River at Colusa for carp and pike minnow. In 2000, the Sacramento River at Colusa rainbow trout had no OCl exceedances of OEHHA screening values. Toxaphene was not measured and dieldrin was not measured with adequate analytical sensitivity to determine if it was present at concentrations above OEHHA screening values. Also in 2000, the Sacramento River Watershed Program found that the striped bass had total DDT and total chlordane concentrations below OEHHA screening values. However, the pike minnow were measured with inadequate detection limits for chlordane, while total DDT concentrations were below the OEHHA screening values. For both fish sets sampled, dieldrin was not measured with sufficiently sensitive analytical methods to determine if there were exceedances above the OEHHA screening values. Striped bass had an exceedance of PCBs while the pike minnow's PCB concentration was below the OEHHA screening value. Toxaphene was not measured.

Sutter Bypass. In 1981 through 1984, the TSMP collected catfish and carp from the Sutter Bypass. Five of the six fish collected had excessive DDT compared to the OEHHA screening value. One of these fish had excessive total chlordane. Two of the five fish had excessive dieldrin. The other fish were not analyzed using a method with an adequate sensitivity to dieldrin to determine if there was an exceedance. Three of the six fish had toxaphene and total PCBs above the OEHHA screening value. Sufficiently sensitive analytical methods were not used to determine if excessive toxaphene and PCBs were present in these fish at that time. There has been no recent collection of fish from the Sutter Bypass.

Feather River. In 1980, brown trout, channel catfish, hardhead, rainbow trout, Sacramento squawfish and sucker from the Feather River at Forbestown all contained total PCBs above OEHHA screening values. Forbestown is on the Feather River above Lake Oroville. The other OCls were not analyzed in these fish. The PCB problem that was found in fish in the 1980s in the Feather River at Forbestown has not been further investigated in more recent studies.

Croyle of the CVRWQCB (pers. comm., 2002) has indicated that the high PCBs found in 1980 in fish taken from the South Fork of the Feather River near Forbestown, just upstream of Lake Oroville, were believed to be due to the use of PCB oil that was spread on dirt roads to reduce dust. Harry Rectenwald of the California Department of Fish and Game, Redding Office (pers. comm., 2002), indicated that, while the Department of Fish and Game was active in investigating this matter in the early 1980s, to his knowledge, there have been no recent studies of the PCB content of fish from this area. He indicated that there is a possibility of much wider contamination of fish by PCBs due to former PCB releases by PG&E power stations located in the area. John Nelson of the Department of Fish and Game (pers. comm., 2002) indicated that he was not aware of any recent data on PCBs in fish from this area. He indicated that PG&E was collecting fish for analysis in the early 1980s.

The TSMP, in 1980, obtained samples of brown trout from the Feather River South Fork at Woodleaf and measured PCBs with inadequate analytical sensitivity to determine if they were present at concentrations above OEHHA screening values. The other OCls were not measured. The TSMP also collected brown trout from the Feather River South Fork at Golden. PCBs were found at levels above the OEHHA screening value. Again, total DDT, dieldrin, chlordane and toxaphene were not measured. Sacramento squawfish in 1980 and 1990 were obtained from the Feather River North Fork at Pulga. PCBs were measured with inadequate detection limits. In 1980, rainbow trout and Sacramento squawfish were taken from the Feather River North Fork at Belden. PCBs were measured with inadequate detection limits, while the other OCls were not measured. The TSMP sampled brown trout in 1980 from the Feather River North Fork at Richbar. Again, total DDT, dieldrin, chlordane and toxaphene were not measured, while PCBs were not measured with adequate analytical sensitivity to determine if they were present at concentrations above OEHHA screening values.

From the information available, there is need for current studies on the PCB content of fish from the South Fork of the Feather River above Lake Oroville.

Fish from the Feather River at the Highway 99 Bridge had been periodically analyzed from 1978 through 1980. Some of the fish taken from the Feather River at the Highway 99 Bridge in the 1980s contained excessive concentrations of total DDT, dieldrin, total chlordane and total PCBs. The sampling of Feather River fish at the Highway 99 Bridge has not been continued.

Feather River at Nicolaus was sampled for Asiatic clam in 1995 by the USGS. Nicolaus is just upstream of where the Feather River joins the Sutter Bypass. None of the OCls measured were above the OEHHA screening values. However, inadequate analytical detection limits were used by the USGS to measure dieldrin, chlordane, toxaphene and total PCBs in the fish samples at the OEHHA screening values. The Sacramento River Watershed Program analyzed Feather River fish at Nicolaus from 1997 through 2000. White catfish taken from the Feather River at Nicolaus in 1997 did not contain excessive concentrations of OCls compared to OEHHA screening values. Largemouth bass taken in 1998 also did not contain excessive OCls. Pike minnow and largemouth bass were collected from the Feather River near Nicolaus in 1999. The largemouth bass contained PCBs just at the screening value. The pike minnow collected in 1999 did not contain excessive PCBs. In 2000, pike minnow did not contain excessive OCls.

Jack Slough at Highway 70. In 1995, the USGS sampled Asiatic clam in Jack Slough at Highway 70. Total DDT was found at concentrations below the OEHHA screening value. They did not use adequate analytical sensitivity for dieldrin, chlordane, toxaphene or PCBs to determine if they were present at concentrations above OEHHA screening values.

Yuba River. A carp taken in 1978 as part of the TSMP was found to contain total DDT above the OEHHA screening value. All other OCls measured in the carp were below OEHHA screening values. The USGS, in 1995, sampled ruffle sculpin and Asiatic clam in the Yuba River near Marysville. They did not use adequate analytical sensitivity for total DDT, dieldrin, chlordane, toxaphene or PCBs to determine if they were present at concentrations above OEHHA screening values.

Bear River. Green sunfish were sampled from the Bear River in 1982 by the TSMP and were found to have no excessive levels of the measured OCls. In 1995, the USGS sampled Sacramento sucker from the Bear River. The concentration of total DDT was below OEHHA screening values. However, the analytical detection limits used for measuring dieldrin, chlordane, toxaphene and total PCBs were above the OEHHA screening values.

East Canal near Nicolaus. The USGS obtained carp from the East Canal near Nicolaus in 1995. Total DDT and dieldrin were above the OEHHA screening values. They did not use adequate analytical sensitivity for chlordane, toxaphene or PCBs to determine if they were present at concentrations above OEHHA screening values.

Sacramento Slough. Sacramento Slough fish were sampled in 1998, 1999 and 2000 as part of the Sacramento River Watershed Program. The 1998 and 1999 fish sampling, which included largemouth bass and white catfish, did not contain excessive concentrations of any of the OCls investigated, including PCBs. However, in 2000, white catfish and largemouth bass taken from Sacramento Slough contained excessive concentrations of PCBs. Excessive concentrations of dieldrin were found in the white catfish sample. Toxaphene was not measured. Total DDT and chlordane were found below the OEHHA screening values.

Sacramento River at Verona. In 1995, the USGS sampled Asiatic clam and found that the concentrations of total DDT were below the OEHHA screening value. The other OCls and PCBs were not measured with adequate analytical sensitivity to determine if they were present at concentrations above OEHHA screening values.

Colusa Basin Drain. One of the listed Waterbodies for excessive OCl bioaccumulation is the Colusa Basin Drain. Colusa Basin Drain drains irrigation tailwater and stormwater runoff from irrigated areas in the Central Sacramento Valley. Fish from the Colusa Basin Drain have been sampled in various locations, which include Colusa Basin Drain/Abel Road, Colusa Basin Drain at the Yolo Colusa County Line and Colusa Basin Drain at Knight's Landing. Herein, the data for these locations are indicated as Colusa Basin Drain data. Data have been collected on the fish tissue concentrations of OCls from the Colusa Basin Drain from 1980-1988 for various types of catfish, carp and sucker. All of the fish collected from the Colusa Basin Drain in the early 1980s, except for the sucker, contained excessive total DDT. Figure 15 presents the total DDT data for the Colusa Basin Drain from 1980-2000. The various locations in the Colusa Basin Drain where samples have been taken for the types of fish sampled are designated through symbol and color codes on this figure. The USGS sampled carp, taken in 1995, and found that they contained excessive total DDT, dieldrin and toxaphene above the OEHHA screening values. Examination of Figure 15 shows that carp collected in 1998 and 2000, as part of the Sacramento River Watershed Program, also contained excessive total DDT. White catfish, collected in 2000, had a DDT concentration below the OEHHA screening value.

As shown in Figure 16, all of the 1980 fish samples collected from the Colusa Basin Drain for which there were adequately sensitive detection limits showed excessive dieldrin. The more recently collected carp also contained excessive dieldrin above the OEHHA screening values. Dieldrin was not measured with sufficient sensitivity on white catfish collected in 2000.

Two of the eight fish obtained in the Colusa Basin Drain in the 1980s contained excessive total chlordane. Sufficiently sensitive analytical methods were not used on all of the fish at that time to measure exceedances above the OEHHA screening value for chlordane. The recently collected fish from the Colusa Basin Drain showed that one sample of carp did not contain excessive chlordane. However, for the white catfish and another carp, sufficiently sensitive analytical methods were not used to detect exceedances.

The analytical methods used by the TSMP in the early 1980s generally did not detect toxaphene at the OEHHA screening value. However, a brown bullhead and a channel catfish, collected in 1980 and 1984, did have excessive toxaphene. As shown in Figure 17, in 1995, a carp taken from the Colusa Basin Drain contained excessive

Figure 15

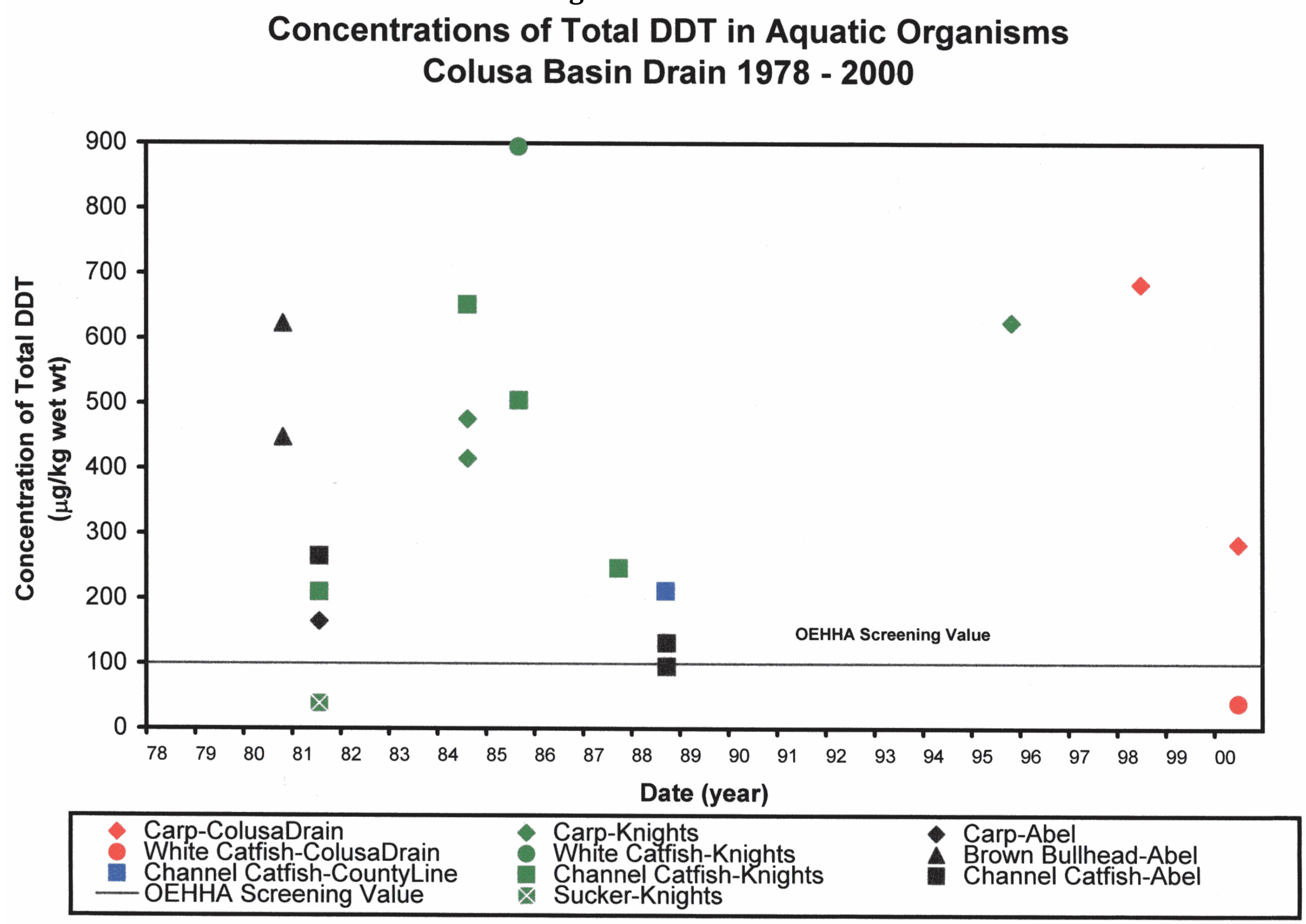
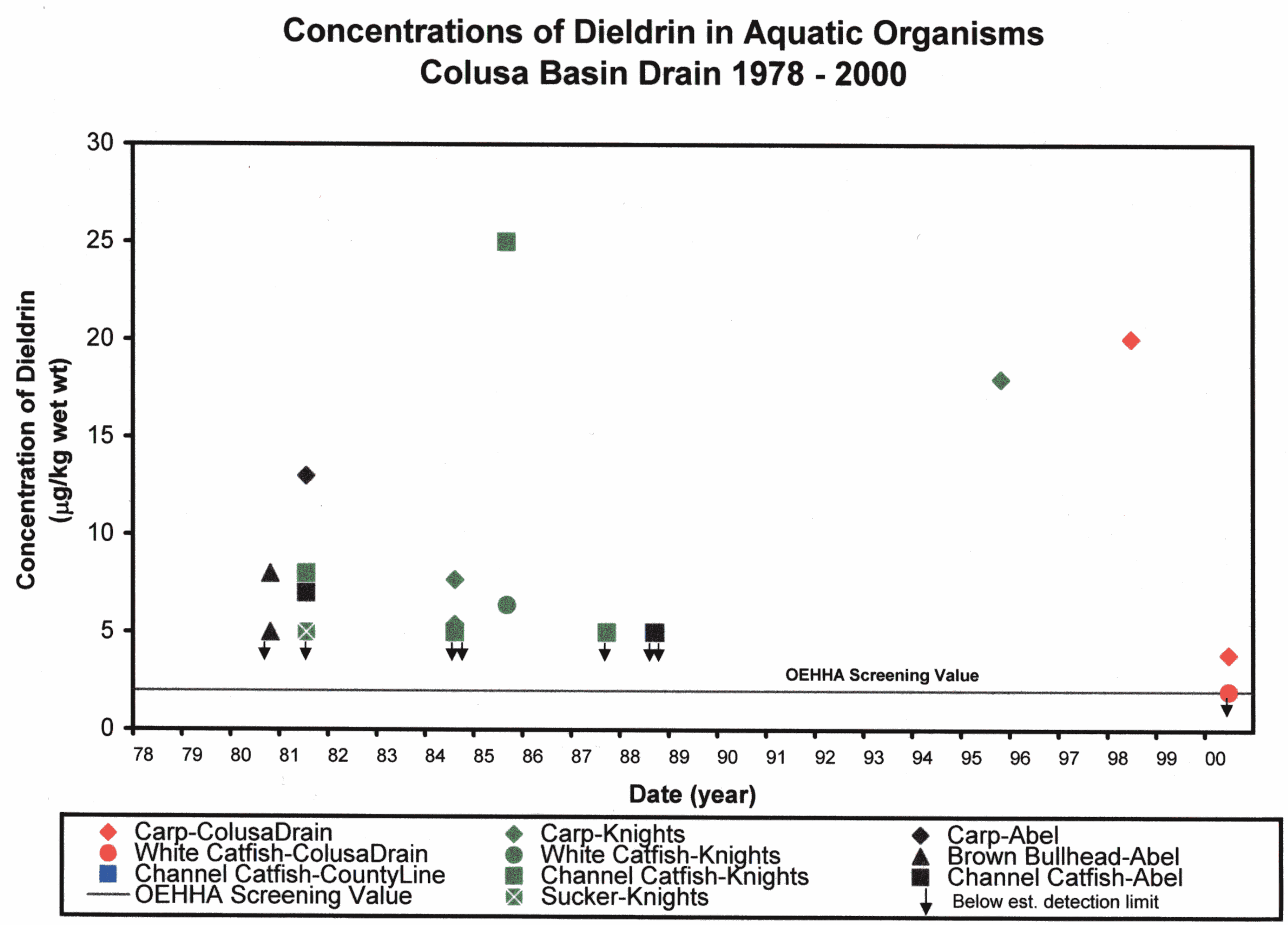
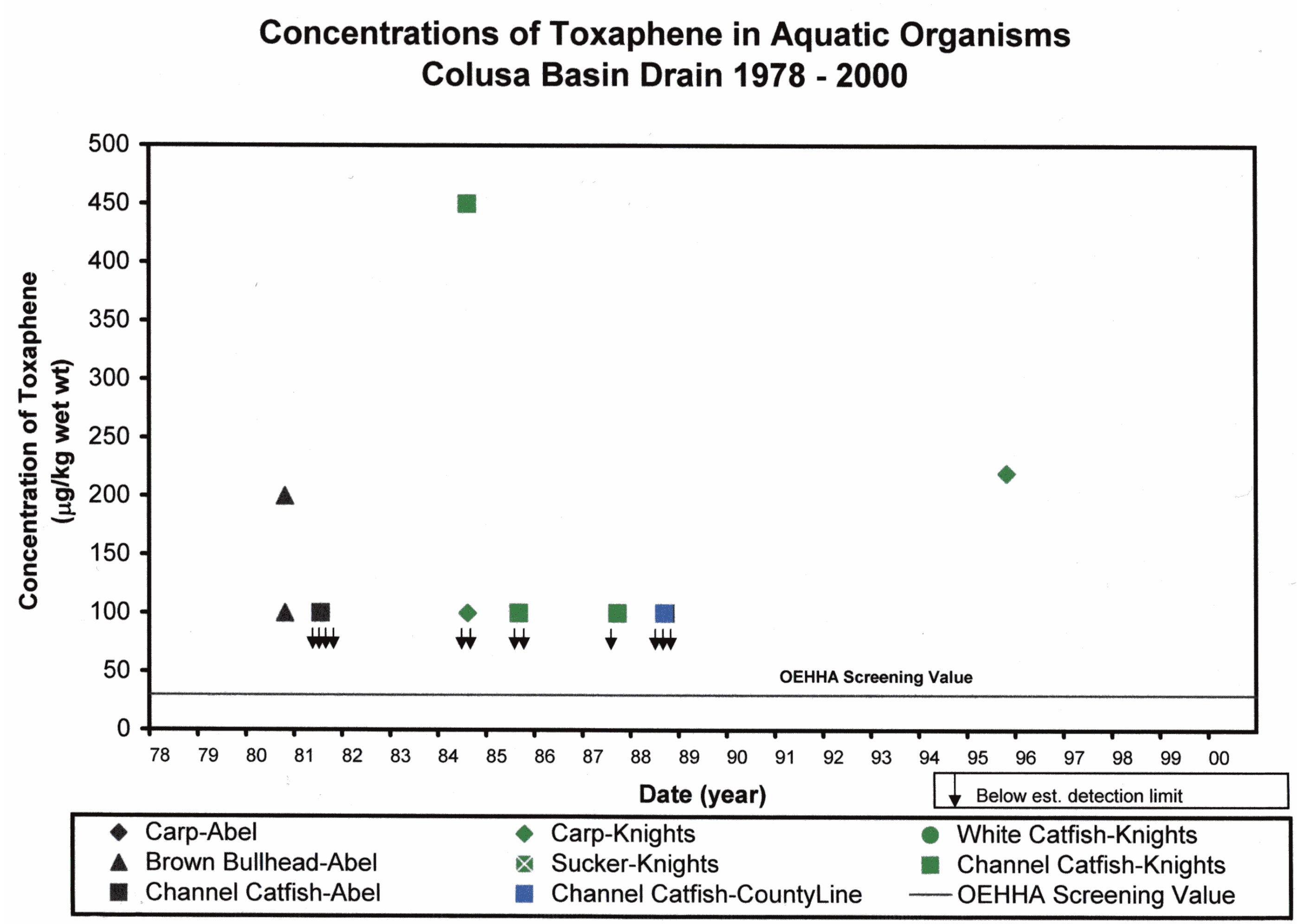

Concentrations of Total DDT in Aquatic Organisms
Colusa Basin Drain 1978 - 2000
Concentration of Total DDT (µg/kg wet wt)
900
800
700
600
500
400
300
200
100
0
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00
Date (year)
OEHHA Screening Value
Carp-ColusaDrain
White Catfish-ColusaDrain
Channel Catfish-CountyLine
OEHHA Screening Value
Carp-Knights
White Catfish-Knights
Channel Catfish-Knights
Sucker-Knights
Carp-Abel
Brown Bullhead-Abel
Channel Catfish-Abel

Figure 16



Concentrations of Dieldrin in Aquatic Organisms
Colusa Basin Drain 1978 - 2000
Concentration of Dieldrin (µg/kg wet wt)
30
25
20
15
10
5
0
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00
Date (year)
OEHHA Screening Value
Carp-ColusaDrain
White Catfish-ColusaDrain
Channel Catfish-CountyLine
OEHHA Screening Value
Carp-Knights
White Catfish-Knights
Channel Catfish-Knights
Sucker-Knights
Carp-Abel
Brown Bullhead-Abel
Channel Catfish-Abel
Below est. detection limit

Figure 17


Concentrations of Toxaphene in Aquatic Organisms
Colusa Basin Drain 1978 - 2000
Concentration of Toxaphene (µg/kg wet wt)
500
450
400
350
300
250
200
150
100
50
0
OEHHA Screening Value
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00
Date (year)
Below est. detection limit
Carp-Abel
Brown Bullhead-Abel
Channel Catfish-Abel
Carp-Knights
Sucker-Knights
Channel Catfish-CountyLine
White Catfish-Knights
Channel Catfish-Knights
OEHHA Screening Value

toxaphene. There have been no measurements of toxaphene in more recently collected fish from the Colusa Basin Drain.

As shown in Figure 18, in the 1980s, some brown bullhead, channel catfish and carp taken from the Colusa Basin Drain were also found to contain excessive total PCBs above the OEHHA screening value. Carp collected in 1998 and white catfish collected in 2000 from the Colusa Basin Drain did not contain excessive PCBs.

Sacramento River at Veteran's Bridge. At Veteran's Bridge in 2000, the Sacramento River Watershed Program obtained pike minnow and white catfish. These samples were found to have exceedances of PCBs above OEHHA screening values. DDT and chlordane were below the OEHHA screening value. Dieldrin was not measured with sufficiently sensitive analytical methods to determine if there were exceedances above the OEHHA screening values. Toxaphene was not measured.

Natomas East Main Drain. Natomas East Main Drain is an agricultural tailwater and stormwater drain for part of the Sacramento River watershed. Carp, sucker, and bluegill were sampled in 1985 and 1986 by the TSMP from Natomas East Main Drain. Carp, compared to the OEHHA screening values, contained excessive total DDT, total chlordane, and PCBs. For all three fish sampled, dieldrin and toxaphene were not measured with sufficiently sensitive analytical procedures to determine exceedances of the OEHHA screening value. The sucker and bluegill collected in 1985 and 1986 did not contain excessive total DDT. Figure 19 shows that the white catfish and largemouth bass, collected from Natomas East Main Drain in the late 1990s and 2000, did not contain total DDT above the OEHHA screening value.

Figure 20 shows that carp collected in 1985 contained excessive chlordane, while the sucker collected at that time did not contain excessive chlordane. The concentration of chlordane in the bluegill sample was below the detection limit, which was below the OEHHA screening value. The recently collected largemouth bass also did not contain excessive chlordane.

In 1985, the total PCBs were above the OEHHA screening value for carp and sucker taken from the Natomas East Main Drain. Sufficiently sensitive analytical procedures were not used to determine the concentration of PCBs in the bluegill sample at the OEHHA screening value. Figure 21 shows that the recently collected largemouth bass and white catfish from Natomas East Main Drain contained total PCBs above the OEHHA screening value.

Arcade Creek. Arcade Creek is an urban creek located on the north side of Sacramento. Its current watershed is largely residential, although at one time, much of this area was devoted to agriculture. The USGS sampled Asiatic clam in Arcade Creek in 1995. Dieldrin and total chlordane were present in the clam tissue above the OEHHA screening value. Total DDT was found at concentrations below the OEHHA screening value. Inadequate detection limits were used for toxaphene and total PCBs to determine if Arcade Creek Asiatic clams contained excessive concentrations of these OCls.

Figure 18

Concentrations of Total PCBs in Aquatic Organisms
Colusa Basin Drain 1978 - 2000

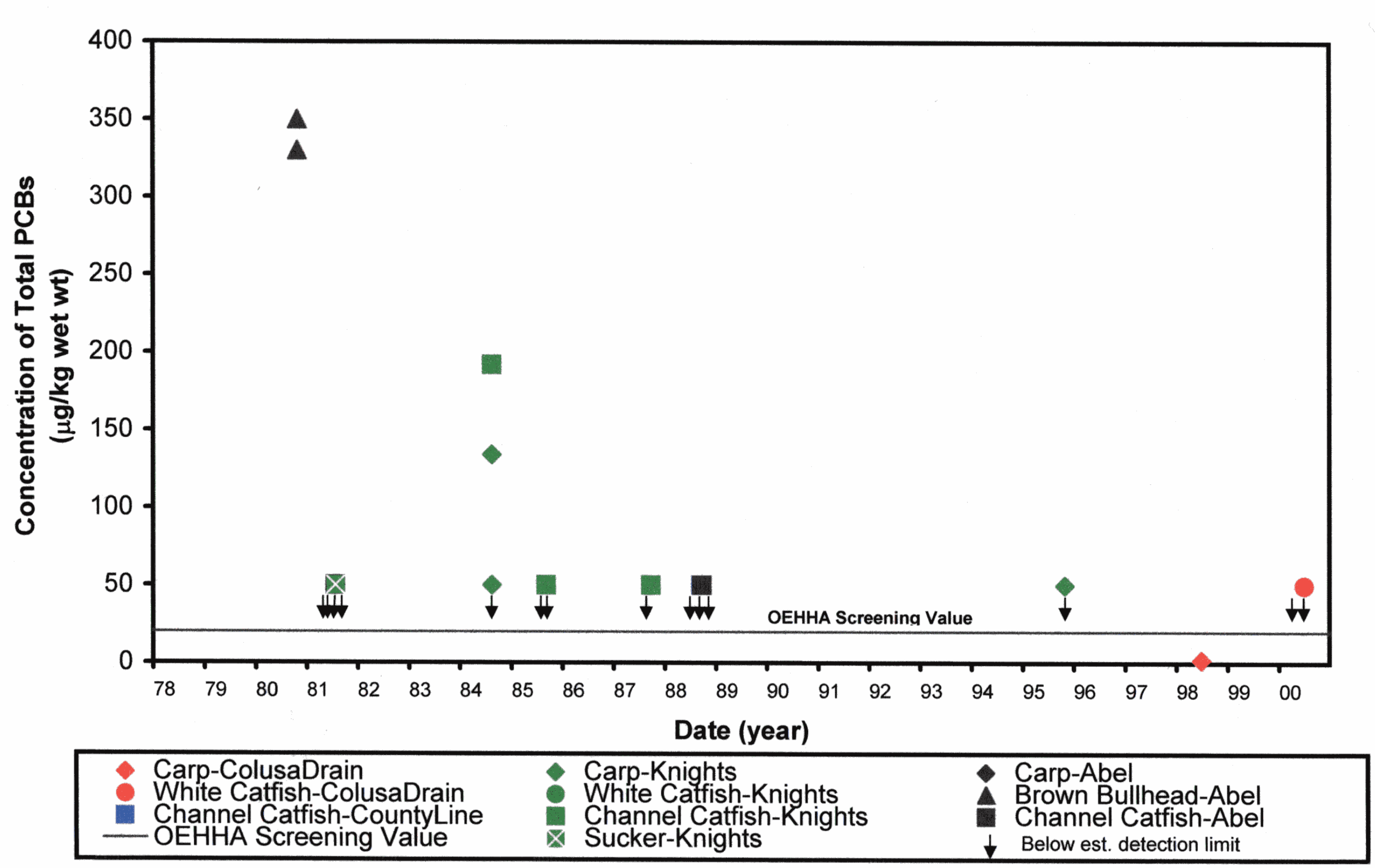


Figure 19

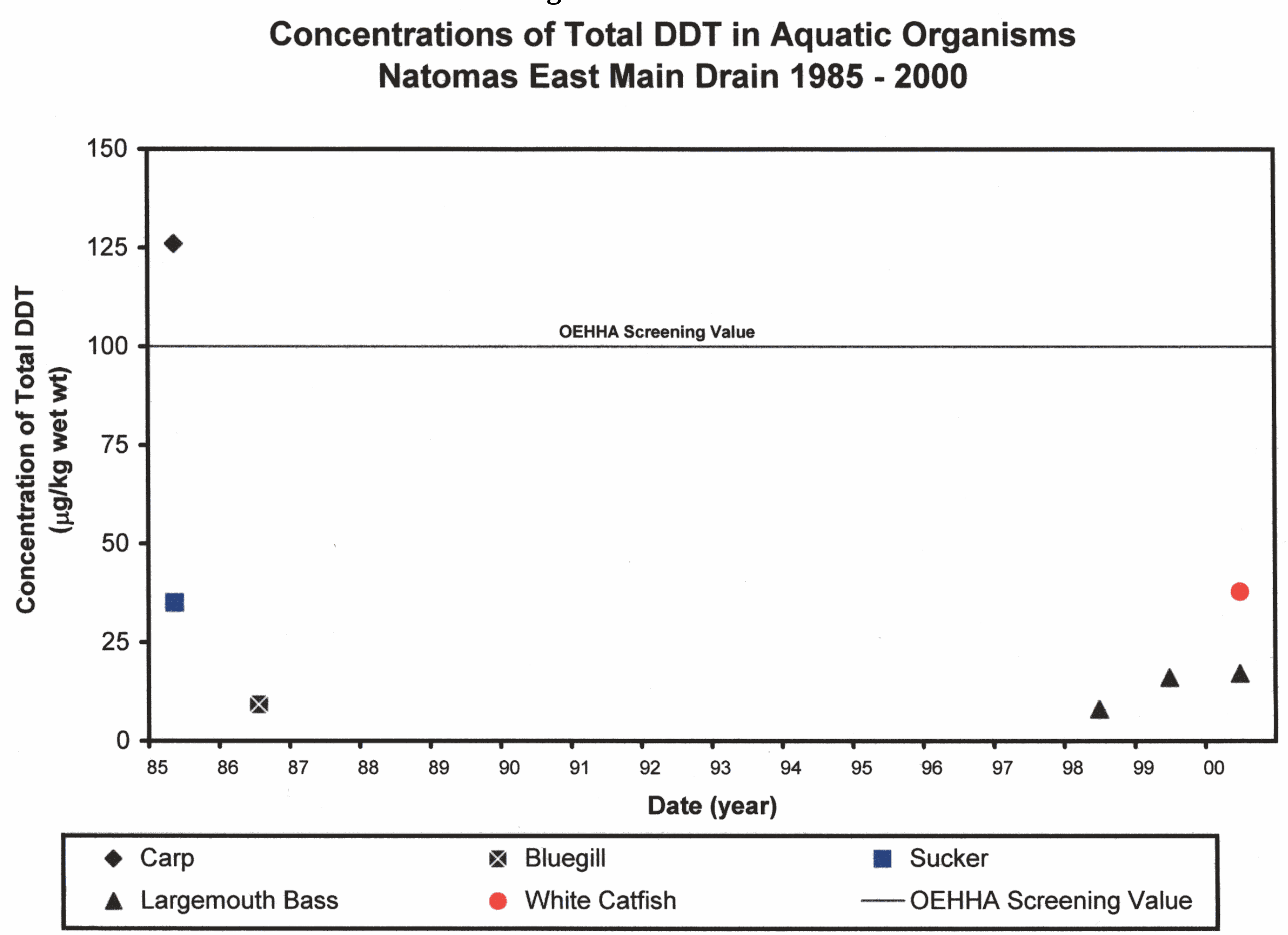

Concentrations of Total DDT in Aquatic Organisms
Natomas East Main Drain 1985 - 2000
Concentration of Total DDT (µg/kg wet wt)
150
125
100
75
50
25
0
OEHHA Screening Value
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
00
Date (year)
Carp
Bluegill
Sucker
Largemouth Bass
White Catfish
OEHHA Screening Value

Figure 20

Concentrations of Total Chlordane in Aquatic Organisms Natomas East Main Drain 1985 - 2000

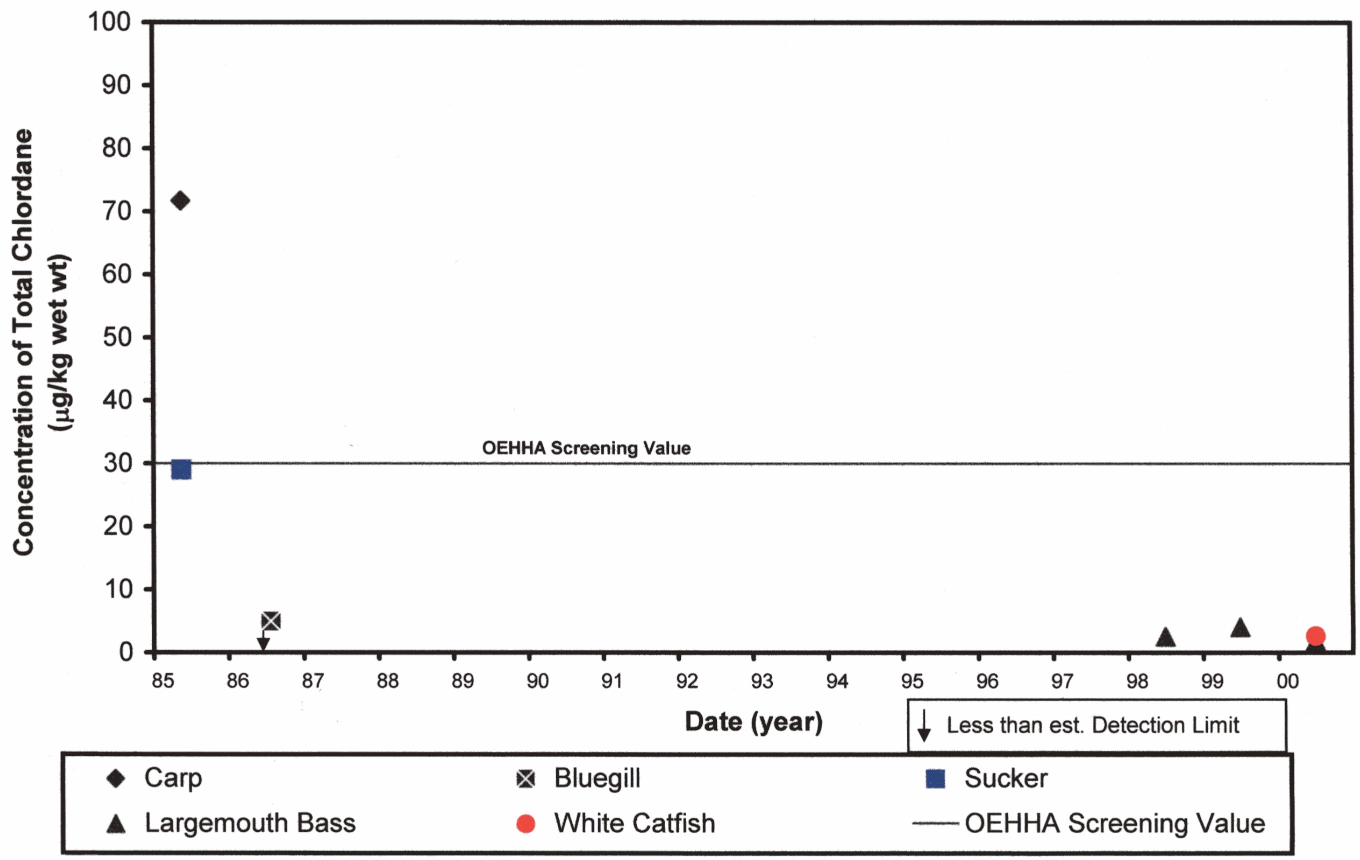
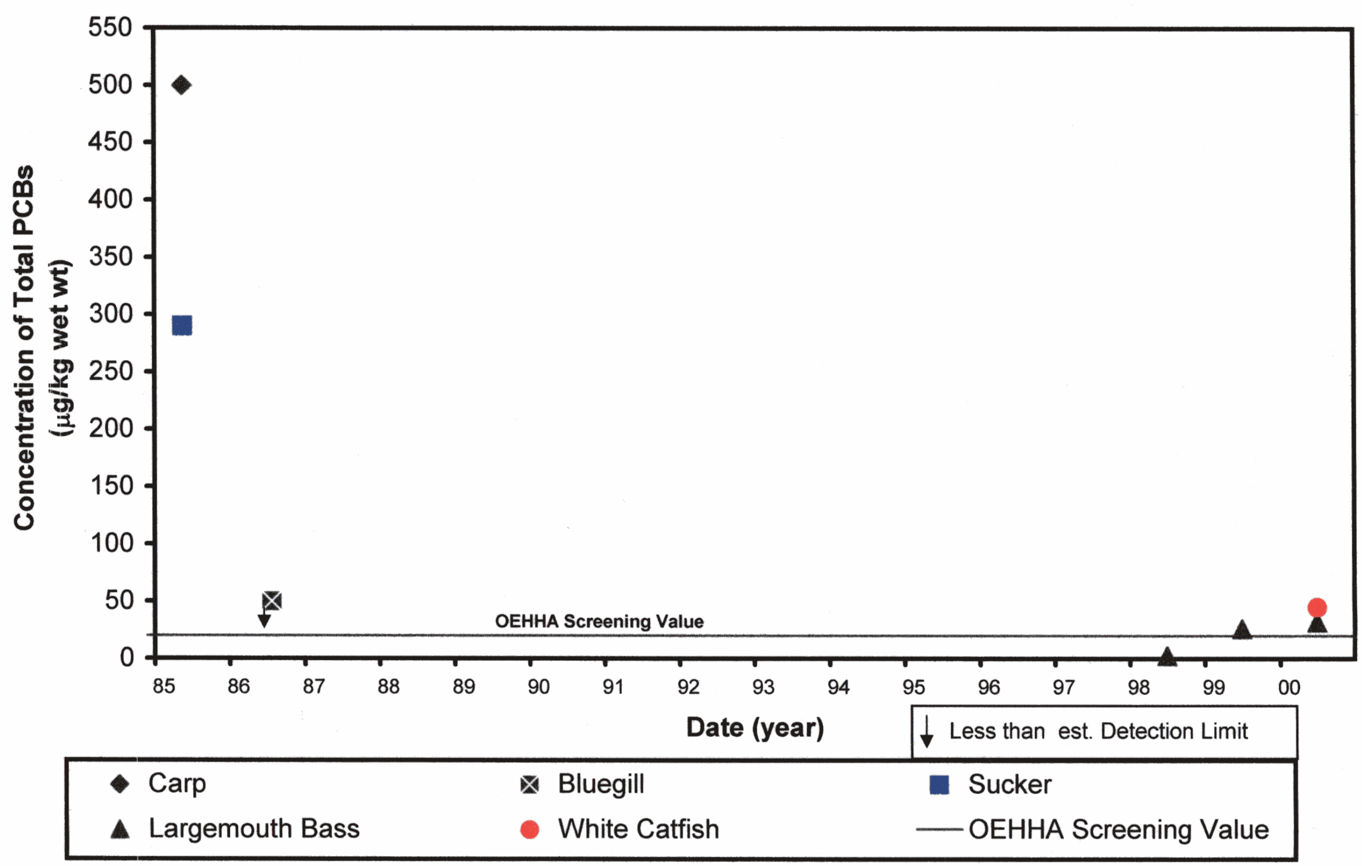


Figure 21

Concentrations of Total PCBs in Aquatic Organisms
Natomas East Main Drain 1985 - 2000



Lower American River. During the late 1970s and early 1980s (including one sample in 1991), the TSMP sampled various types of fish and other organisms in the American River at Watt Avenue. Figure 22 presents the total DDT concentrations in the organisms sampled during this period. Sucker, Sacramento squawfish, and Asiatic clam were found to contain total DDT above the OEHHA screening value. Figure 23 shows that Sacramento squawfish and sucker, taken from the American River at Watt Avenue during the late 1970s and early 1980s, contained total chlordane above the OEHHA screening value. Figure 24 shows that the total PCBs in fish taken from the American River at Watt Avenue were above the OEHHA screening value. Some of the PCB measurements, however, were done with analytical methods that could not detect PCBs at the OEHHA screening value.

In 1995, the USGS sampled Asiatic clam from the American River at "Sacramento, California," and found that total DDT concentrations were below the OEHHA screening values while the other OCls and PCBs were not measured with adequate analytical sensitivity to determine if they were present at concentrations above OEHHA screening values.

More recently, fish and other aquatic life from the American River at other locations than Watt Avenue have been sampled by several programs. In 1987-1988, the USGS found that Sacramento squawfish obtained from the American River at the Highway 160 bridge contained total chlordane above the OEHHA screening value. Also, the squawfish obtained from this location contained total PCBs above the OEHHA screening value. The measurements of toxaphene, heptachlor epoxide and dieldrin by the USGS on this fish sample did not have adequate sensitivity to measure these OCls at the OEHHA screening values.

White catfish, pike minnow, largemouth bass and Sacramento sucker from the American River at Discovery Park were sampled by the Sacramento River Watershed Program from 1997 through 2000. In 1997, white catfish sampled contained dieldrin below the OEHHA screening value, while PCBs were above the screening value. In 1998, pike minnow were sampled. Dieldrin was the only OCl that was found to be above the OEHHA screening value. Total DDT, total chlordane and total PCBs were below the OEHHA screening value. Toxaphene was not measured. In 1999, American River at Discovery Park largemouth bass and Sacramento sucker were sampled. Largemouth bass had excessive PCBs above the OEHHA screening value, while insufficiently sensitive analytical methods for measurements of PCBs were used on the Sacramento sucker. DDT and chlordane in both the largemouth bass and the Sacramento sucker were below the OEHHA screening values. White catfish and largemouth bass were sampled in 2000. Again, total DDT and total chlordane were below the OEHHA screening values. PCBs were excessive compared to the OEHHA screening values, while toxaphene was not measured with sufficiently sensitive analytical methods to determine if there were exceedances above the OEHHA screening values.

Figure 22

Concentrations of Total DDT in Aquatic Organisms
American River at Watt Avenue 1978 - 2000

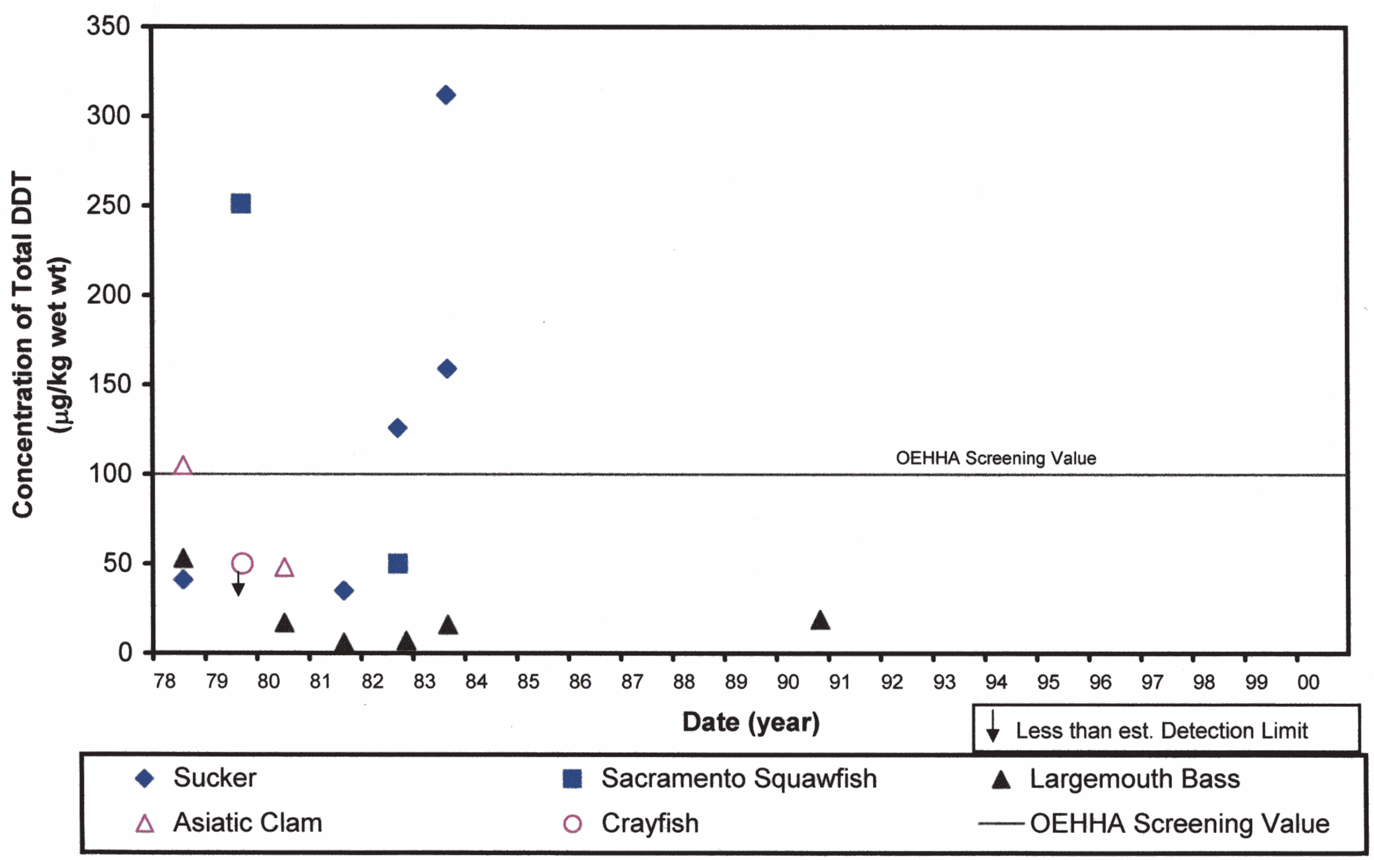


Figure 23

Concentrations of Total Chlordane in Aquatic Organisms American River at Watt Avenue 1978 - 2000

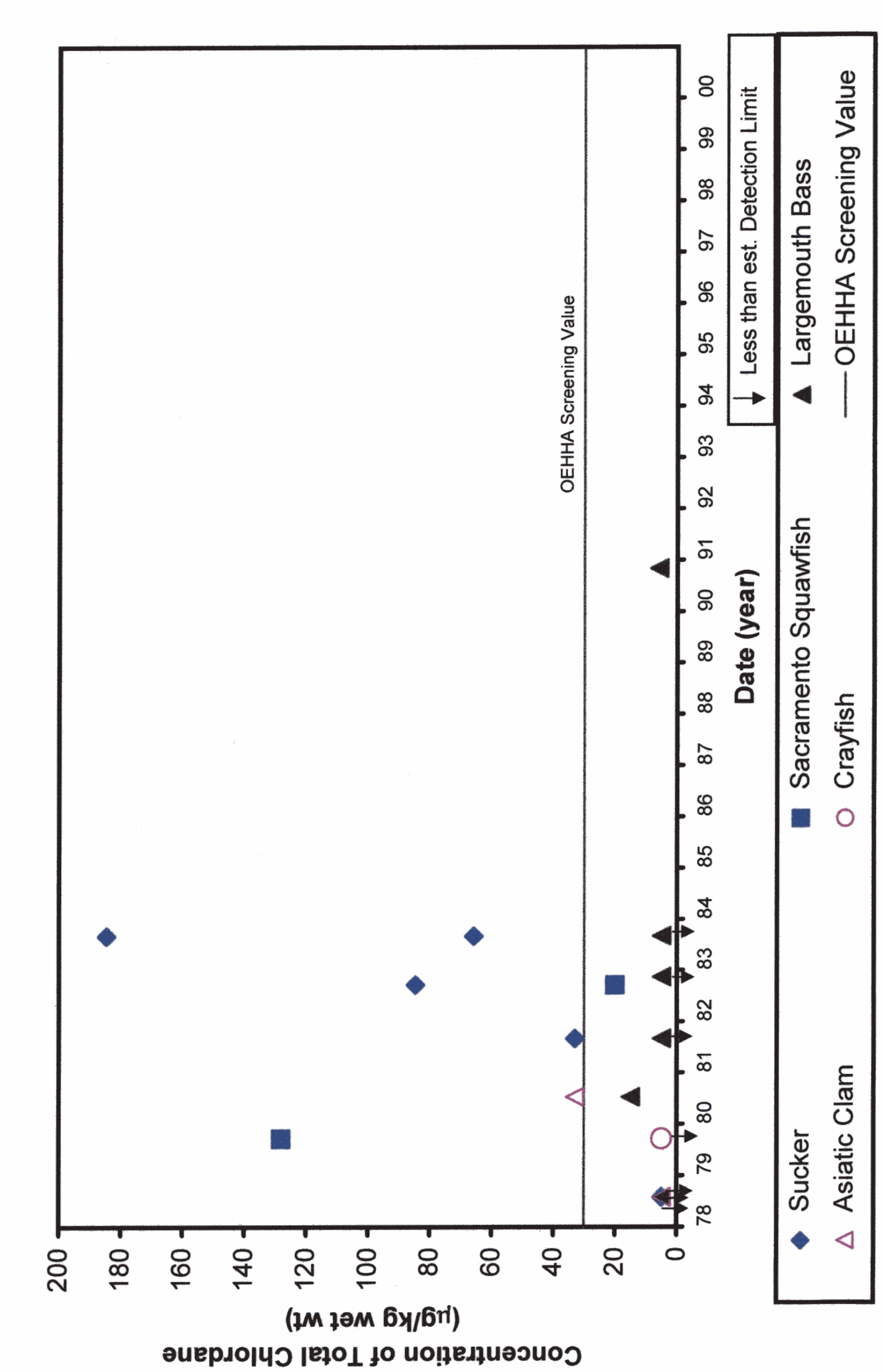
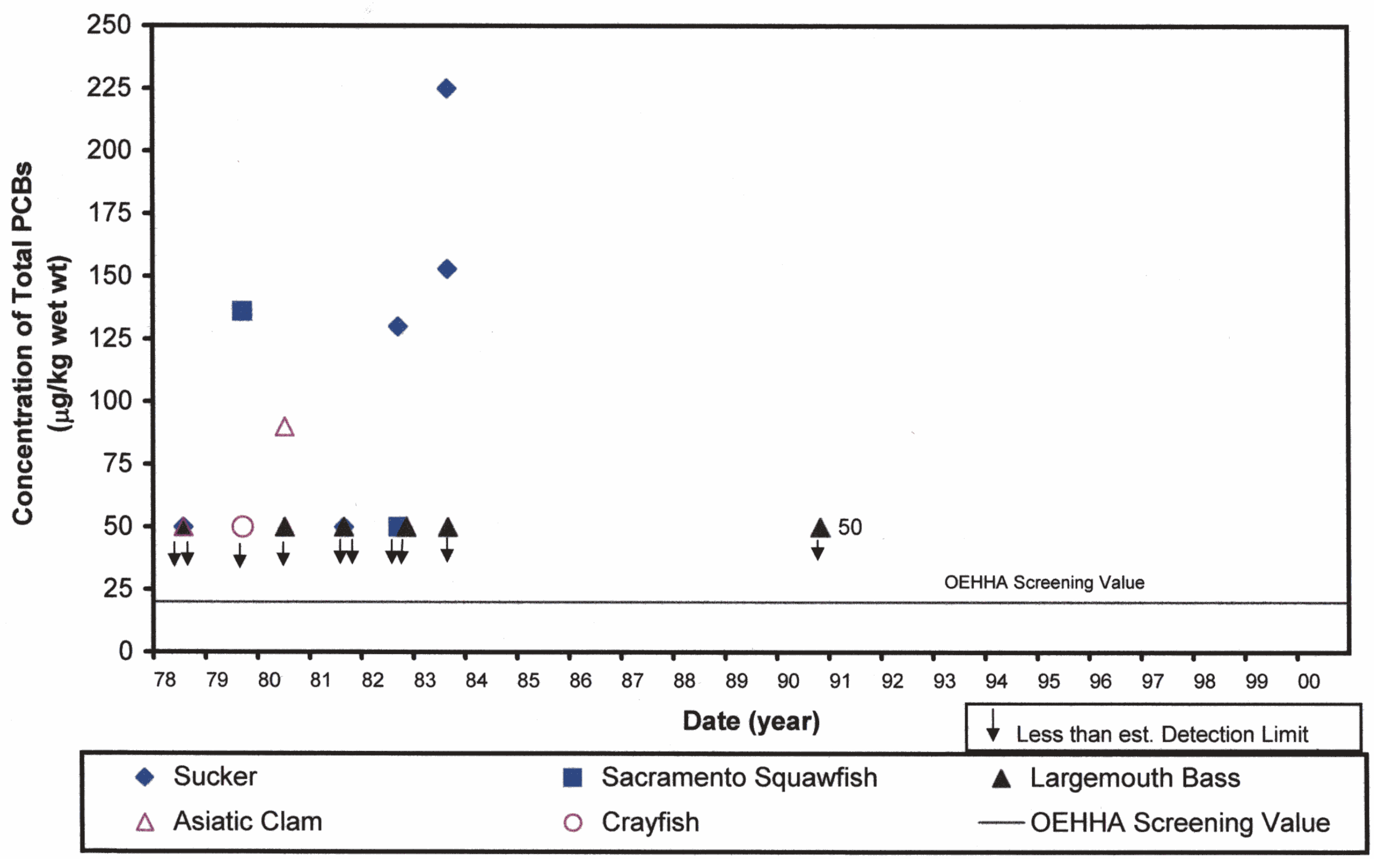


Figure 24

Concentrations of Total PCBs in Aquatic Organisms
American River at Watt Avenue 1978 - 2000



In 1999, Sacramento sucker taken from the American River at J Street were analyzed with inadequate detection limits for dieldrin, chlordane and PCBs to determine exceedances of the OEHHA screening values. However, the other OCls were measured below the value. In 2000, Sacramento sucker and pike minnow were sampled. Total DDT and total chlordane were below the screening values. Inadequate methods for dieldrin were used. The Sacramento sucker had levels of PCBs below the OEHHA screening value. However, with the pike minnow sample, PCBs were found to be above this value. Toxaphene was not measured.

The CVRWQCB (2000) has recommended that the American River be de-listed for Group A pesticides. From the additional data available, it appears that the de-listing of the American River for Group A pesticides may be appropriate. However, several of the Group A pesticides have not been measured with adequate analytical sensitivity in American River fish to determine if they are present at concentrations above OEHHA screening values. There is an issue as to whether the Lower American River should be listed for excessive PCBs, since fish taken from this river have been found in recent years to contain excessive PCBs compared to OEHHA screening values.

Sacramento River at Freeport. In 1995, the USGS collected Asiatic clams from the Sacramento River at Freeport. Total DDT was below the OEHHA screening value, while the other OCls and PCBs were measured with inadequate analytical sensitivity to determine if they were present at concentrations above OEHHA screening values.

Sacramento River at Mile 44. The Sacramento River at Mile 44 station was not sampled as part of the TSMP from 1978 through the 1980s. It has been sampled from 1997 through 2000 by the Sacramento River Watershed Program. All but one set of white catfish, largemouth bass, Sacramento sucker and pike minnow obtained during 15 sampling events from 1997 through 2000 had a total DDT less than the OEHHA screening value. The white catfish sample collected in 1998 had total DDT above the screening value. The dieldrin data, presented in Figure 25, show a couple of white catfish samples with concentrations above the OEHHA screening value. Most of the values were reported as less than the detection limit, which was below the screening value. Chlordane concentrations were below the OEHHA screening value. Toxaphene was not measured.

Figure 26 presents the total PCBs found in various types of fish taken from the Sacramento River at Mile 44 during the period 1997 through 2000. There were a number of white catfish, largemouth bass and Sacramento sucker with concentrations of total PCBs above the OEHHA screening value.

Sacramento River at Hood. Sacramento River at Hood station is located downstream of the city of Sacramento. This station is one of the primary monitoring stations for OCl bioaccumulation in fish in the lower Sacramento River. Figure 27 presents the total DDT concentrations found in fish from this location for the period 1978 through 1998. As shown, there are many values over the years with concentrations of total DDT in white catfish above the OEHHA screening value. Figure 28 shows that, in 1998, dieldrin was

Figure 25

Concentrations of Dieldrin in Aquatic Organisms
Sacramento River at Mile 44 1997 - 2000

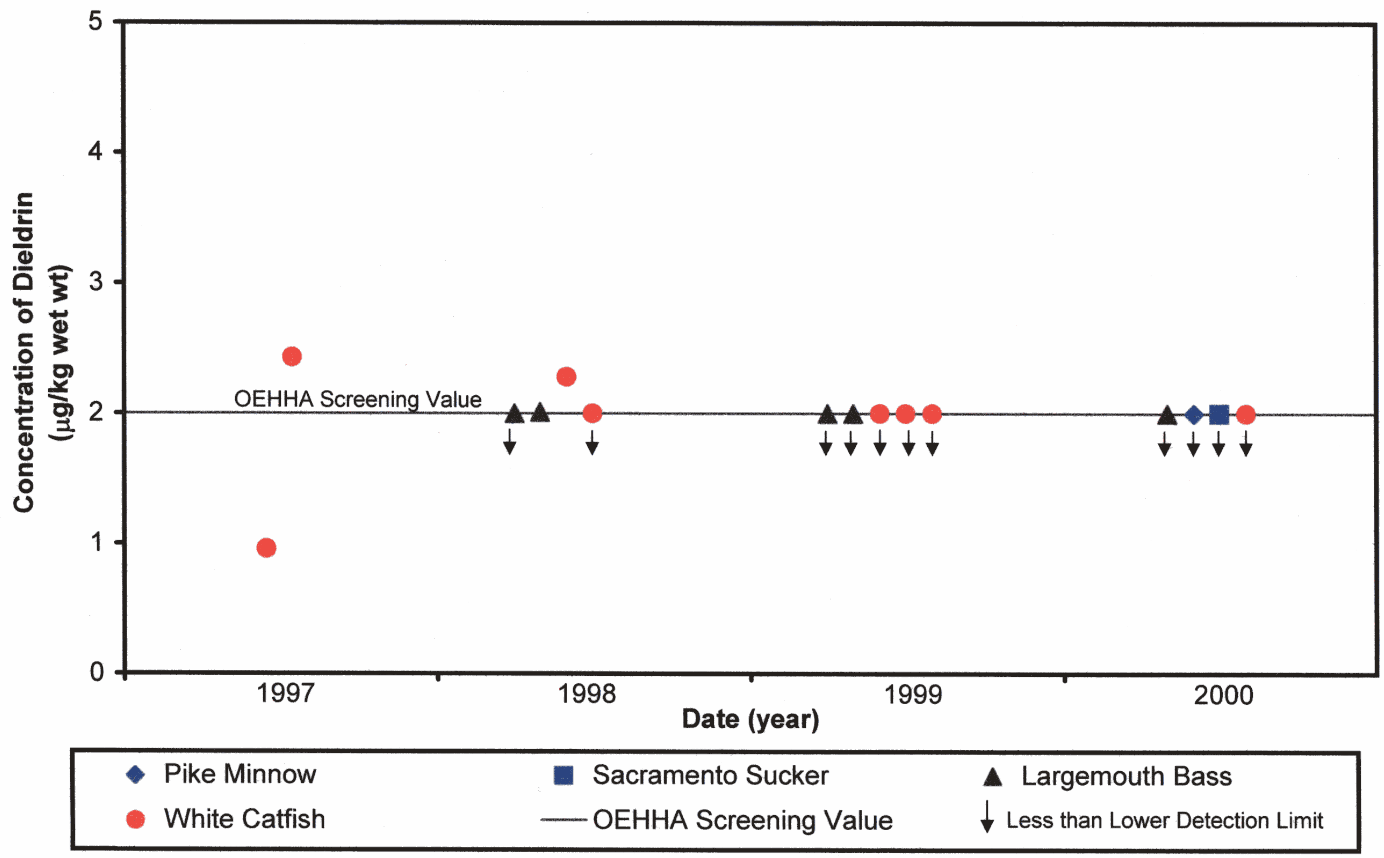


Figure 26

Concentrations of Total PCBs in Aquatic Organisms Sacramento River at Mile 44 1997 - 2000

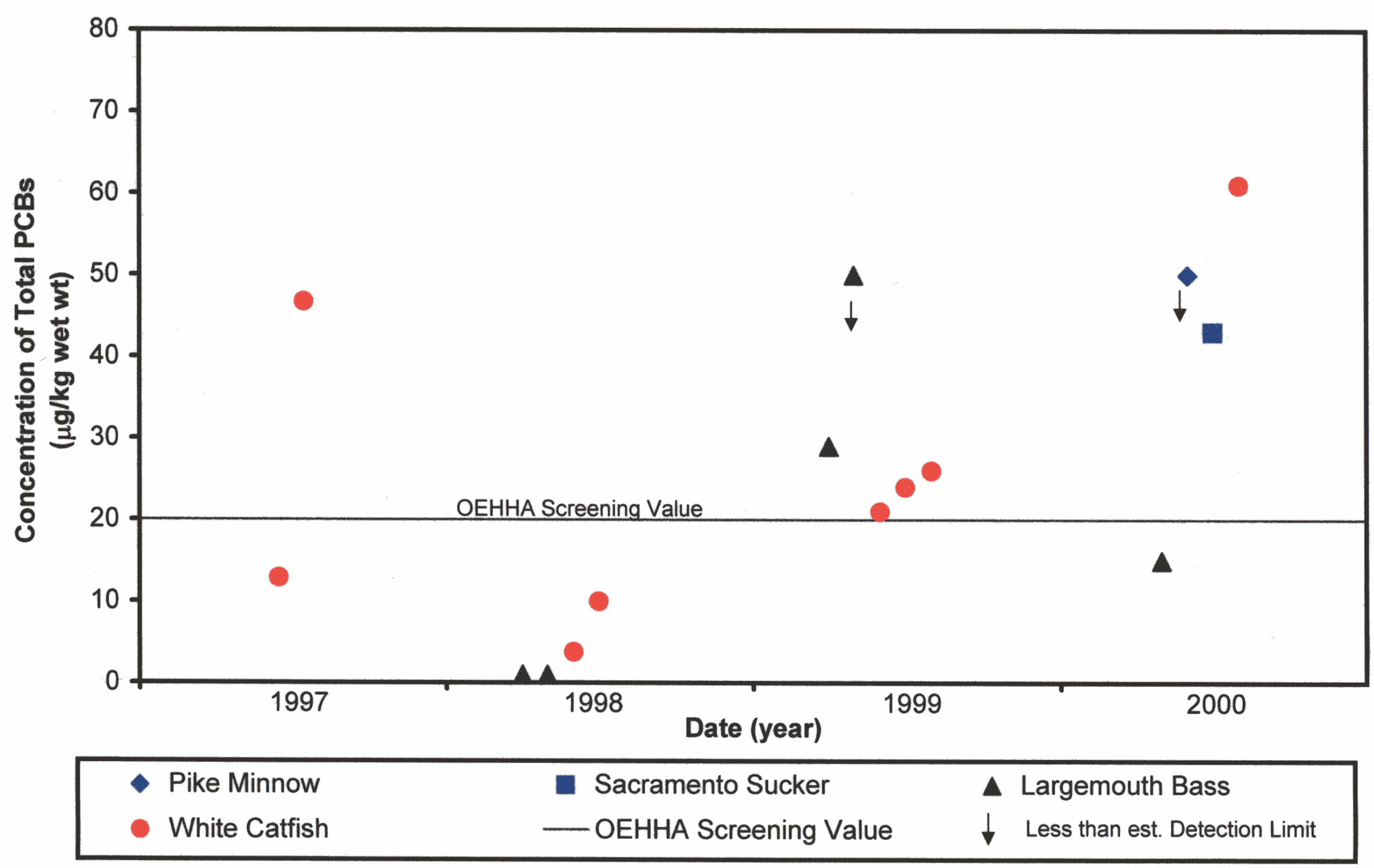


Figure 27

**Concentrations of Total DDT in Aquatic Organisms
Sacramento River at Hood 1978 - 2000**

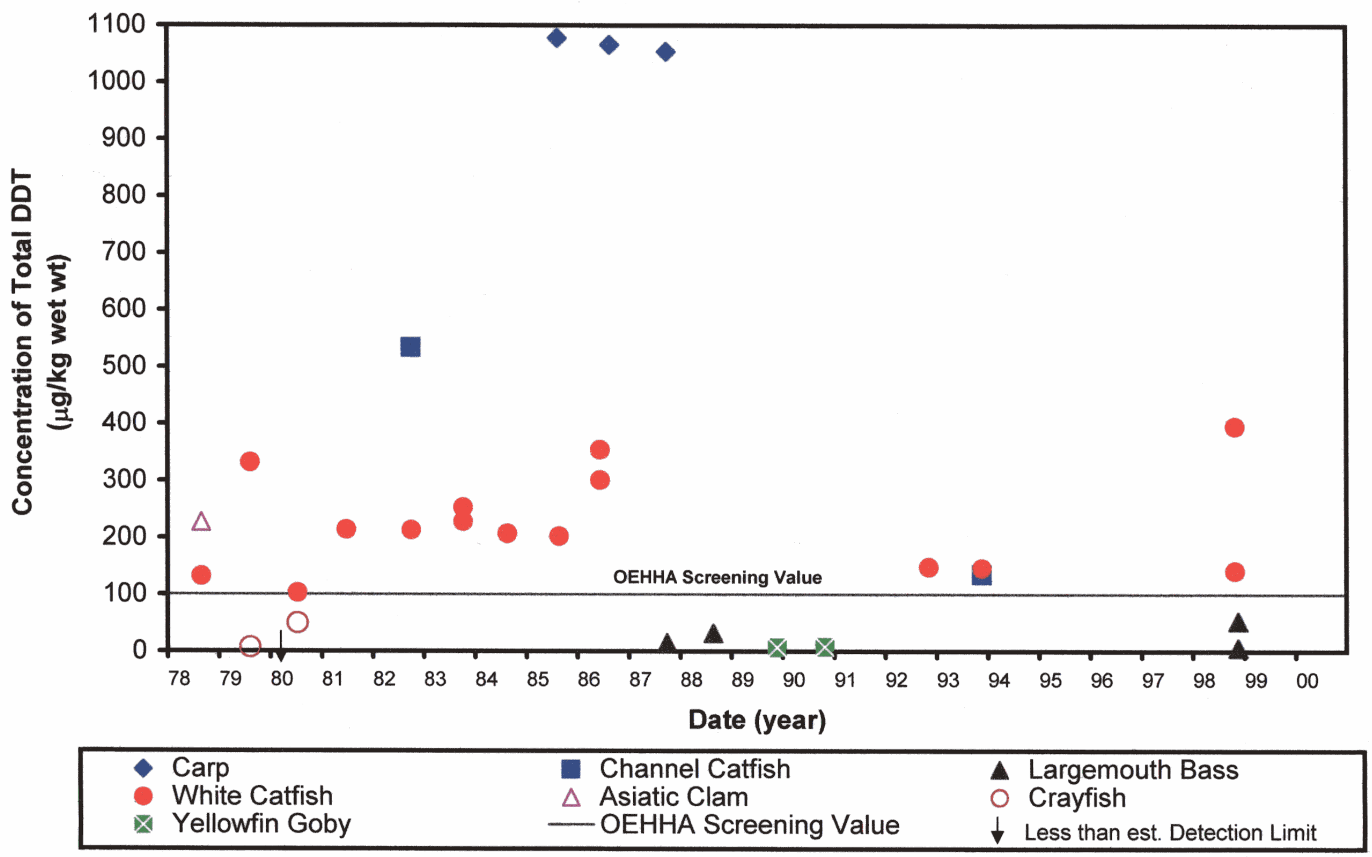
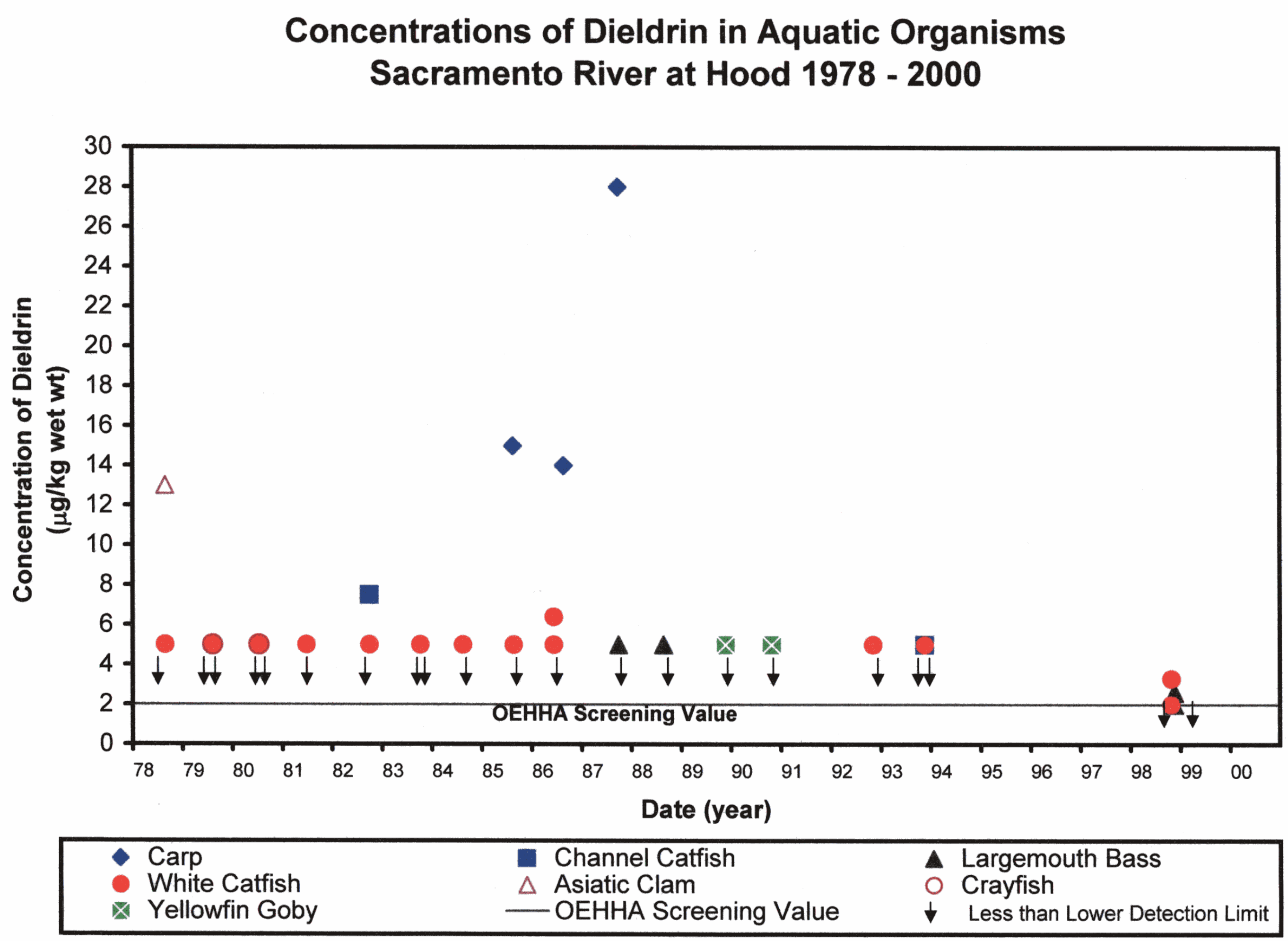


Figure 28


Concentrations of Dieldrin in Aquatic Organisms
Sacramento River at Hood 1978 - 2000
Concentration of Dieldrin (µg/kg wet wt)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
OEHHA Screening Value
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
00
Date (year)
Carp
White Catfish
Yellowfin Goby
Channel Catfish
Asiatic Clam
OEHHA Screening Value
Largemouth Bass
Crayfish
Less than Lower Detection Limit

present in white catfish and largemouth bass taken from the Sacramento River at Hood above the OEHHA screening value. Some of the white catfish taken from this location in 1998 had excessive concentrations of total chlordane (Figure 29) and toxaphene (Figure 30). Total PCBs (Figure 31) in white catfish and largemouth bass taken from the Sacramento River at Hood station in 1998 had concentrations above OEHHA screening values.

Cache and Putah Creeks. Cache Creek and Putah Creek are important lower Sacramento River tributaries. They discharge to the Yolo Bypass. Historically, in 1978 through 1981, the concentrations of the OCls measured in the fish and other organisms taken from these creeks did not exceed OEHHA screening values.

TSMP data from 1999 show that sucker taken from Putah Creek had a DDT concentration below OEHHA screening values. However, largemouth bass had excessive DDT. In largemouth bass taken in 1999, chlordane was measured at a concentration below the OEHHA screening value. Inadequate detection limits were used for chlordane measured in the sucker. Both sucker and largemouth bass analytical methods had insufficient sensitivity for measurements of dieldrin. Largemouth bass were just under the OEHHA screening value for PCBs. Analytical methods used on the sucker had inadequate detection limits for chlordane, toxaphene and PCBs. In largemouth bass samples taken in 1999, chlordane and toxaphene were not measured with sufficiently sensitive analytical methods to determine if there were exceedances above the OEHHA screening values.

In 1995, the USGS sampled Sacramento sucker from Cache Creek at Guinda. Dieldrin, toxaphene, and total PCBs were less than the detection limits, which were above the OEHHA screening values. They found that total DDT and total chlordane were less than the OEHHA screening values. Overall, it can be concluded that, at this time, based on the limited sampling that has been done, except for DDT in Putah Creek, neither Cache nor Putah Creek fish have been found to contain excessive concentrations of OCls. However, a number of the OCls of particular concern, such as chlordane that is discharged from the University of California, Davis, Department of Energy national LEHR Superfund Site, located on the UCD campus, have not been measured with sufficiently sensitive analytical methods. Chlordane has been found to be discharged to Cache Creek from the LEHR site at concentrations above the US EPA water quality criterion that could bioaccumulate to excessive levels in Putah Creek fish.

Cache Slough. As part of the Sacramento River Watershed Program, Cache Slough fish were sampled in 1998, 1999 and 2000. In 1998, largemouth bass had measurements of DDT, chlordane, and PCBs below the OEHHA screening values. However, dieldrin exceeded the OEHHA screening value. Toxaphene was not measured. White catfish and largemouth bass were sampled from Cache Slough in 1999 and 2000. Largemouth bass were analyzed with inadequate detection limits for chlordane and PCBs, while the white catfish had concentrations of chlordane and PCBs below the OEHHA screening values. DDT concentrations were below the OEHHA screening values in both sets of fish

Figure 29

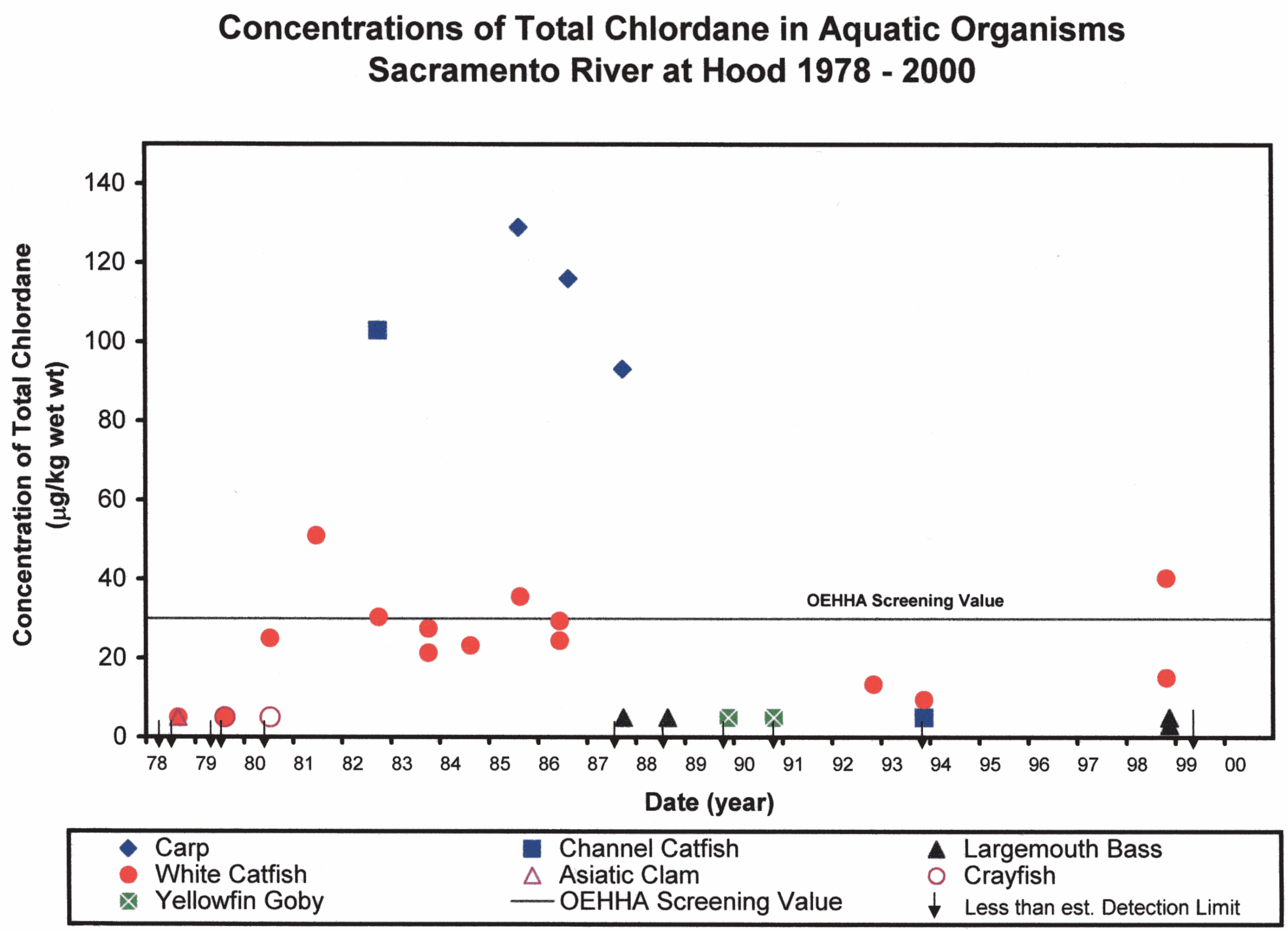

Concentrations of Total Chlordane in Aquatic Organisms
Sacramento River at Hood 1978 - 2000
Concentration of Total Chlordane (µg/kg wet wt)
140
120
100
80
60
40
20
0
OEHHA Screening Value
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
00
Date (year)
Carp
White Catfish
Yellowfin Goby
Channel Catfish
Asiatic Clam
OEHHA Screening Value
Largemouth Bass
Crayfish
Less than est. Detection Limit

Figure 30

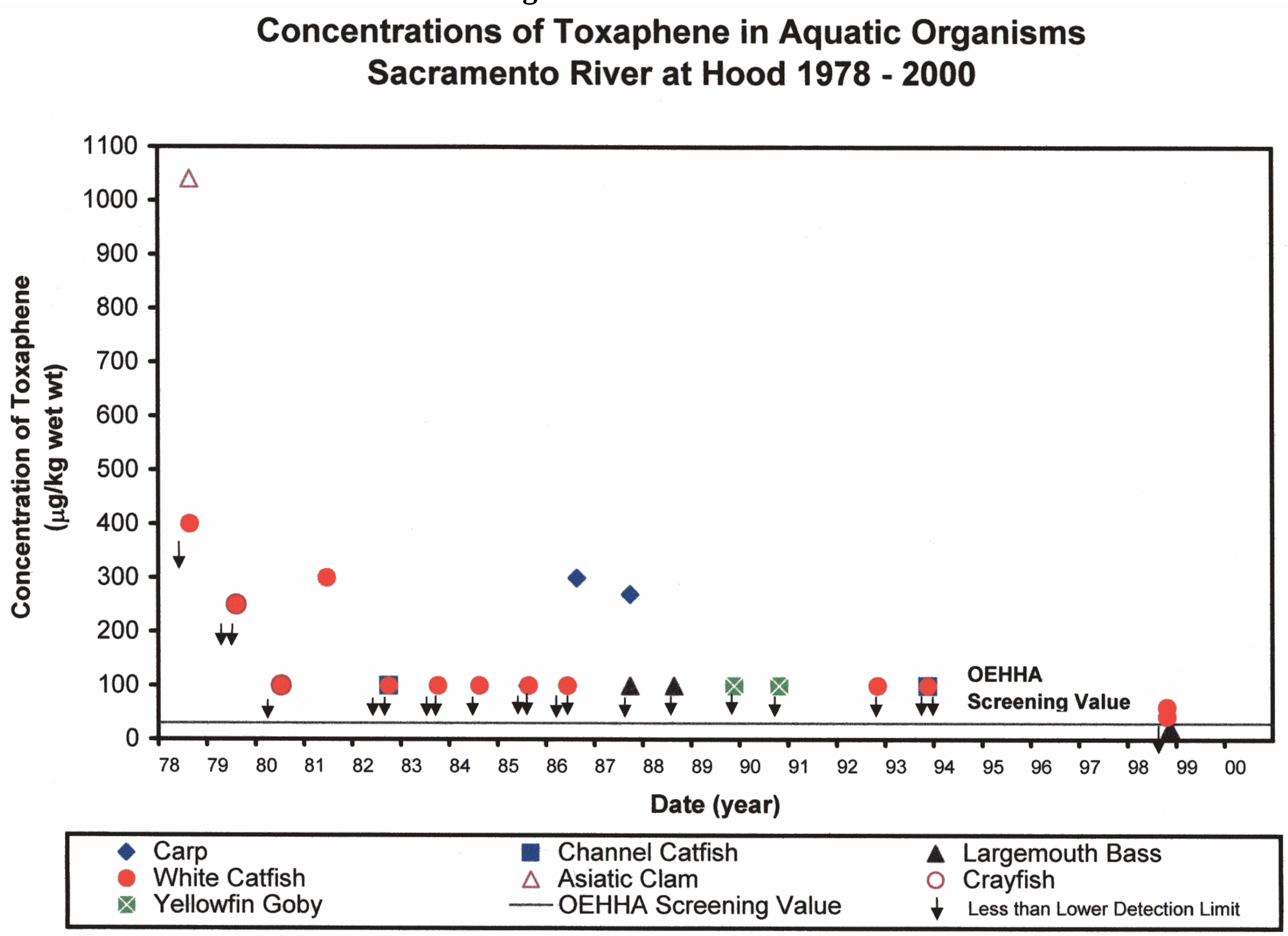
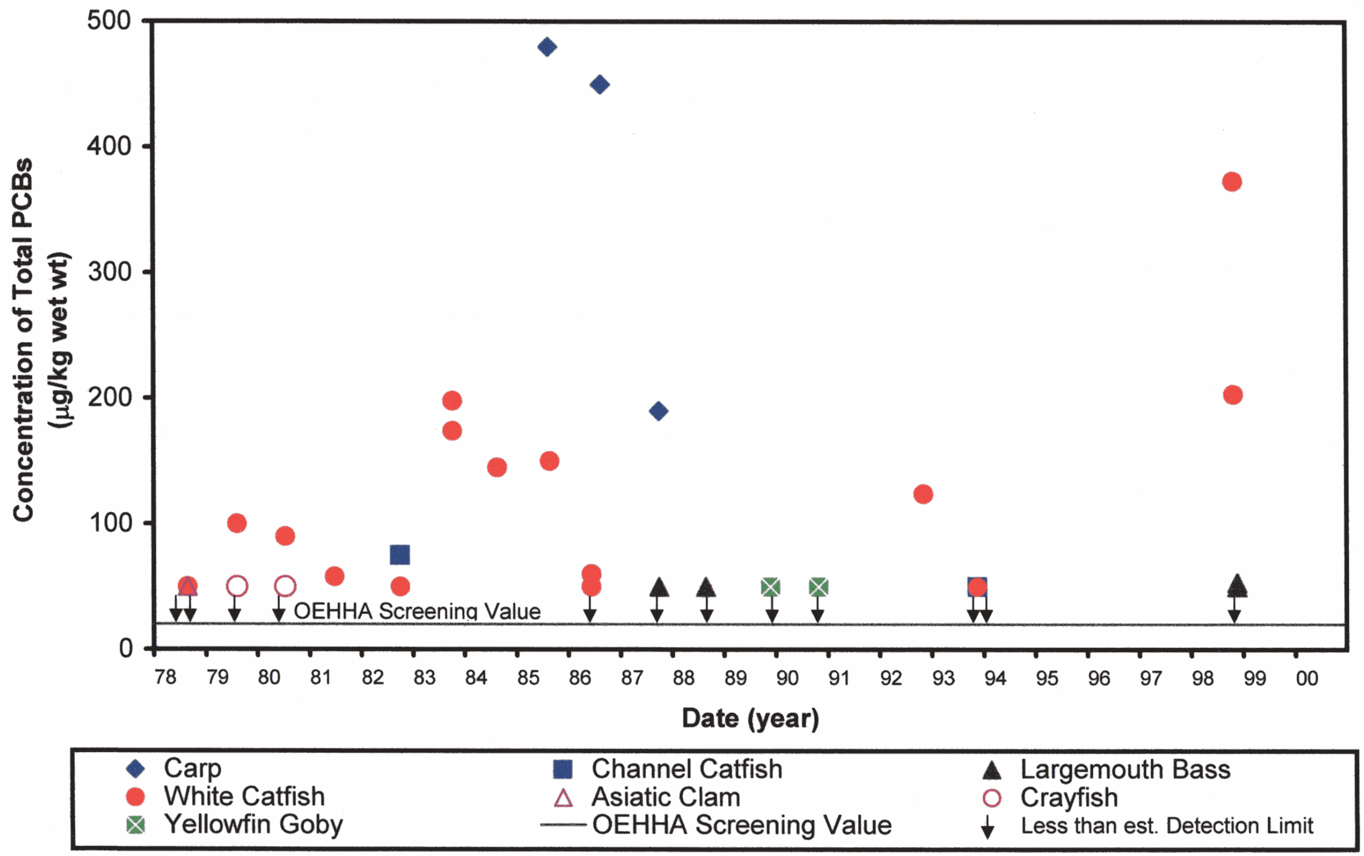

Concentrations of Toxaphene in Aquatic Organisms
Sacramento River at Hood 1978 - 2000
Concentration of Toxaphene (µg/kg wet wt)
1100
1000
900
800
700
600
500
400
300
200
100
0
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
00
Date (year)
OEHHA Screening Value
Carp
White Catfish
Yellowfin Goby
Channel Catfish
Asiatic Clam
OEHHA Screening Value
Largemouth Bass
Crayfish
Less than Lower Detection Limit

Figure 31

Concentrations of Total PCBs in Aquatic Organisms
Sacramento River at Hood 1978 - 2000



sampled. Dieldrin was not measured with sufficiently sensitive analytical methods to determine if there were exceedances above the OEHHA screening values.

Sacramento River at Rio Vista. DeltaKeeper/SFEI sampled *Corbicula fluminea* from the Sacramento River at Rio Vista in 1998. They found that the total DDT and total PCBs were less than the screening values. Dieldrin, chlordane, and toxaphene analyses were conducted with methods that did not have an adequate detection limit to determine if there were exceedances of the OEHHA screening value.

Delta

The Delta is formed by the confluence of the Sacramento and San Joaquin Rivers. It is one of the most important sportfishing recreational areas in the state. A summary of the data obtained on the OCl concentrations in fish taken from the Delta is presented below.

Port of Stockton Turning Basin. In 1998, largemouth bass and white catfish were collected by DeltaKeeper/SFEI from the Port of Stockton Turning Basin. Total DDT and total chlordane were present at concentrations below the OEHHA screening values in the largemouth bass sample. The white catfish sample contained total DDT above the OEHHA screening value. Total chlordane was not present in the white catfish at an excessive level. Dieldrin and toxaphene analyses were conducted with methods that did not have an adequate detection limit to determine if there were exceedances of the OEHHA screening value. However, total PCBs were present in several of the largemouth bass taken from the Port of Stockton Turning Basin above the OEHHA screening value.

White catfish and largemouth bass were collected from “Stockton Deep Water Channel” in 1986 and 1990. The only OCl measured with adequate detection limits was total DDT. It was found that total DDT was less than the OEHHA screening value in these fish.

Port of Stockton near Mormon Slough. DeltaKeeper/SFEI sampled *Corbicula fluminea* from the Port of Stockton near Mormon Slough in 1998. Mormon Slough enters the canal that connects McLeod Lake with the Turning Basin. Mormon Slough is of interest, since this is the area of the McCormick and Baxter Superfund site (US EPA, 2002a), which has discharged sufficient PCBs and dioxins to cause the San Joaquin County Department of Health to post this area for excessive PCBs and dioxins in fish. Total DDT was less than the OEHHA screening value. Dieldrin and total PCBs were above the OEHHA screening values. The other OCls were not measured with adequate detection limits.

Smith Canal. Smith Canal is a freshwater tidal slough, located within the city of Stockton. It is one of the primary waterway conveyance systems of city of Stockton stormwater runoff. DeltaKeeper/SFEI sampled Smith Canal white catfish and largemouth bass at Yosemite Lake in 1998. Yosemite Lake is at the head of Smith Canal. It receives City storm sewer discharges. Total DDT and total chlordane were less than the OEHHA screening value in both kinds of fish. However, total PCBs were above the OEHHA screening value in both white catfish and largemouth bass taken from Smith Canal at Yosemite Lake. Dieldrin and toxaphene analyses were conducted with methods that do not have an adequate detection limit to determine if there were exceedances of the OEHHA screening value.

San Joaquin River around Turner Cut. In 1998, DeltaKeeper/SFEI sampled largemouth bass and white catfish from the San Joaquin River “around Turner Cut.” This location is about seven miles downstream of the Port of Stockton Turning Basin within the Deep Water Ship Channel. Total DDT, total chlordane and total PCBs were all below OEHHA screening values in both types of fish analyzed. Again, inadequate detection limits were used for dieldrin and toxaphene.

White Slough downstream from Disappointment Slough. White Slough is on the eastern part of the mid-Delta. In 1998, DeltaKeeper/SFEI sampled largemouth bass and black bullhead at White Slough downstream from Disappointment Slough. Total DDT and total PCBs were less than the OEHHA screening values. Dieldrin, chlordane, and toxaphene were not measured with sufficiently sensitive analytical methods to determine if there were exceedances of the OEHHA screening values.

San Joaquin River at Potato Slough. In 1998, DeltaKeeper/SFEI sampled largemouth bass and white catfish from San Joaquin River at Potato Slough, which is between Disappointment Slough and Antioch Point. Total DDT and total chlordane were below OEHHA screening values for both types of fish. Total PCBs were found above the OEHHA screening value in the white catfish sample. Inadequate sensitivity was used in the PCB analysis of the largemouth bass sample. Dieldrin and toxaphene analyses were conducted with methods that did not have an adequate detection limit to determine if there were exceedances of the OEHHA screening value.

San Joaquin River off Point Antioch. DeltaKeeper/SFEI collected largemouth bass in 1998 from the San Joaquin River off Point Antioch near the fishing pier. There were no exceedances of any of the OCls measured. The same problems occurred with this DeltaKeeper/SFEI study for detection limits for dieldrin, chlordane, and toxaphene. The San Joaquin River below Disappointment Slough is, during the summer, fall and early winter, primarily a mixture of Sacramento River water and releases from Delta islands. This is a result of the state and federal export pumps creating a large cross-Delta flow of the Sacramento River water at Disappointment Slough and Columbia Cut. This cross-Delta flow prevents the San Joaquin River water present upstream of Disappointment Slough/Columbia Cut from proceeding down the San Joaquin River channel. It would only be under high San Joaquin River flows, such as during the late winter/spring, that any significant amount of San Joaquin River water would reach Antioch Point.

Sycamore Slough near Mokelumne River. In 1998, DeltaKeeper/SFEI sampled largemouth bass and black bullhead from Sycamore Slough at Mokelumne River. One largemouth bass taken from this location had dieldrin above the OEHHA screening value.

Total DDT was below the OEHHA screening value, while the analyses for the rest of the OCls were conducted with insufficiently sensitive analytical methods.

Mokelumne River between Beaver and Hog Sloughs. In 1998, DeltaKeeper/SFEI sampled largemouth bass and black bullhead from the Mokelumne River between Beaver and Hog Sloughs. Total DDT and total PCBs were less than the OEHHA screening values. Dieldrin, chlordane, and toxaphene were analyzed with insufficiently sensitive analytical methods to determine if there were exceedances of the OEHHA screening values.

Mokelumne River near Woodbridge. Various organisms were sampled from the Mokelumne River at Woodbridge in 1978-1981. Asiatic clam was the only organism that contained DDT above the OEHHA screening value in 1978. Total DDT was not above the OEHHA screening value in the 1979-1980 sampling for Asiatic clam and largemouth bass. Almost all other OCls at that sampling time and location were analyzed with insufficiently sensitive analytical methods.

In 1992, the USGS sampled Asiatic clam taken from the Mokelumne River near Woodbridge. The concentrations of total DDT were below the OEHHA screening value. The detection limits used for dieldrin, chlordane, toxaphene and total PCBs were inadequate to detect these chemicals at the screening value.

Middle River at Bullfrog. Middle River runs north to south through the middle of the Delta. It connects to the San Joaquin River Channel in the north and to Old River in the south. In 1998, DeltaKeeper/SFEI sampled largemouth bass and white catfish from Middle River at Bullfrog. Total DDT and total PCBs were less than the OEHHA screening values. The analytical methods used for dieldrin, chlordane and toxaphene were not sufficiently sensitive to determine if there were exceedances of the OEHHA screening values.

Old River. Old River connects to the San Joaquin River downstream of Vernalis. At times, appreciable San Joaquin River water is diverted into the South Delta via Old River. White catfish from Old River were sampled by DeltaKeeper/SFEI in 1998. Total DDT and total PCBs were found above the OEHHA screening value. Total chlordane was less then the screening value. Dieldrin and toxaphene were not measured with sufficiently sensitive analytical methods to determine if there were exceedances of the OEHHA screening values. Old River/Tracy fish were also sampled by the TSMP in the mid-1980s. Channel catfish collected in 1984 had excessive DDT concentrations. Total chlordane was less than the OEHHA screening value in channel catfish. The other fish sampled in the 1980s (golden shiner and redear sunfish) had total DDT below the OEHHA screening values. All of the other OCls measured in the fish taken from Old River in the 1980s were analyzed with insufficiently sensitive analytical methods.

Paradise Cut. Paradise Cut is an area of intensive agricultural drainage, located in the South Delta. It is a dead-end slough which connects to Old River. Carp, catfish and largemouth bass from Paradise Cut were obtained by the TSMP in the mid- to late 1980s.

Excessive concentrations of DDT, dieldrin, chlordane, toxaphene, and PCBs were found in these fish. Largemouth bass were sampled by DeltaKeeper/SFEI from Paradise Cut in 1998. These fish did not contain total DDT, total chlordane and total PCBs above the OEHHA screening values. Insufficiently sensitive analytical procedures were used for dieldrin and toxaphene. In 1998, white catfish were also sampled by DeltaKeeper/SFEI from Paradise Cut and were found to have excessive total DDT above the OEHHA screening value.

Old River at Central Valley Pumps. White catfish were collected from Old River near the Central Valley pumps in 1998. While total DDT and toxaphene were above the OEHHA screening value, total chlordane was found to be at concentrations below the OEHHA screening value. Dieldrin and PCBs were not measured with sufficiently sensitive analytical methods to determine if there were exceedances above the OEHHA screening values.

O'Neill Forebay/California Aqueduct. In the early 1980s, the TSMP collected striped bass and white catfish from the O'Neill Forebay/California Aqueduct. Total DDT was found in all of these fish above the OEHHA screening value. Total chlordane was found at concentrations less than the OEHHA screening value. All but one of these fish had dieldrin above the OEHHA screening value. One of the fish had total PCBs above the OEHHA screening value. The other fish were analyzed with inadequate sensitivity to measure PCBs at screening-value concentrations. Also, some of the fish were analyzed for dieldrin and toxaphene with analytical methods that were not sufficiently sensitive.

Tulare Lake Basin

King's River. The King's River is not normally part of the San Joaquin River watershed. It discharges to the Tulare Lake Basin. King's River fish were sampled as part of the 1970s and early 1980s TSMP. In 1978, 1979 and 1980, *Corbicula fluminea* taken from the King's River had concentrations of total DDT above the OEHHA screening value. Largemouth bass sampled at the same time also had a total concentration of DDT above the OEHHA screening value. In 1992, the USGS sampled the King's River using *Corbicula fluminea* and found that the concentrations of all of the OCls were below the OEHHA screening values. However, the detection limits used for dieldrin and total PCBs were inadequate to detect these chemicals at the screening value. The USGS also sampled carp at this location in the same year. The concentrations of total DDT were just above the OEHHA screening value. The detection limits used for dieldrin, chlordane, toxaphene and total PCBs were inadequate to detect these chemicals at the screening value. The King's River was also sampled by the TSMP in 2000. Bluegill and sucker tissue concentrations of all of the pesticides and PCBs of interest were not above the screening values. The detection limits used for dieldrin and toxaphene were inadequate to detect these chemicals at the OEHHA screening value.

Kern River. Fish from the Kern River at Bakersfield were sampled by the TSMP in 1978-1980. While several of the fish were analyzed for total DDT, three of the five fish were analyzed with inadequate detection limits to detect DDT above the OEHHA screening value. One of the fish had total DDT somewhat under the OEHHA screening value. The detection limits used for dieldrin, chlordane and toxaphene were inadequate to detect these chemicals at the OEHHA screening value. PCBs were not determined.

OCls in Water and Suspended Sediments

Because of the high sorption tendency of the OCls, it is expected that they would be primarily transported in creeks and rivers on suspended sediment particles. Ross, *et al.* (1999) reviewed the distribution and mass loading of insecticides in the San Joaquin River during the spring of 1991 and 1992. Kratzer (1998a, 1999) discussed the transport of sediment-bound organochlorine pesticides to the San Joaquin River, California. He conducted a review of the NAWQA data obtained in the 1994-1995 studies of several westside (of the SJR) streams, including Orestimba Creek, Spanish Grant Drain, Olive Avenue Drain, Del Puerto Creek, Ingram Creek and Hospital Creek, and includes data on the San Joaquin River near Vernalis. The westside streams are in an area of intensive agriculture. It is also an area where there are significant erosion problems from the irrigated agriculture.

One of the issues of the USGS NAWQA study was the relative magnitude of dissolved organochlorine pesticides versus those attached to particulates in summer irrigation tailwater-dominated conditions and during winter stormwater runoff. Examination of Tables 8 and 9 show that there were measurable concentrations of p,p'-DDE and dieldrin "dissolved" in the water column. "Dissolved" is defined in the Kratzer study as *"those pesticides that were not removed though centrifugation."* Comparison of the concentrations of DDE to the US EPA (1987) Gold Book numbers for protection of aquatic life (0.001 µg/L for 24-hr average exposure conditions) shows that a number of the measured values were a factor of 10 to 20 times the US EPA guideline value. The corresponding water quality criterion for protection of humans from excessive bioaccumulation of DDT in edible fish, with a cancer risk of one in a million, is 0.024 ng/L.

The US EPA (1987) lists the freshwater chronic criteria for dieldrin as 0.0019 µg/L. These are well less than the dissolved concentrations found in Ingram Creek and Hospital Creek in June 1994. The concentrations found at that time are associated with irrigation tailwater discharges. During the winter, the dissolved concentrations of p,p'-DDE were generally less than 0.01 µg/L – i.e., the detection limit used in the analyses. The important conclusions from the USGS/NAWQA/Kratzer (1998a, 1999) studies are that there is organochlorine pesticide transport during the summer irrigation season and in the winter. During the winter it is primarily associated with particulate matter eroded from the fields. Further, there are sufficient concentrations of apparently dissolved DDE to be toxic to aquatic life.

Kratzer concluded that the instantaneous loads of total DDT, chlordane, dieldrin and toxaphene were substantially greater during winter storm runoff than during the irrigation season. This was related to the fact that the winter storm runoff contained much higher concentrations of suspended sediments. Orestimba Creek was found to be the largest source of total DDT, chlordane, dieldrin and toxaphene to the San Joaquin River in a January 1995 storm. Further, Ingram Creek was found to be the largest source

Table 8
Concentrations of p,p'-DDE and Dieldrin in Selected SJR Westside Tributaries During Irrigation Season (June 22, 1994)

Site	Flow (cfs)	Suspended Sediment Concentration (mg/L)	On Suspended Sediment (µg/kg)		Dissolved in Water Column (µg/L)		Concentration in Water Column (µg/L)	
			P,p'-DDE	dieldrin	p,p'-DDE	dieldrin	p,p'-DDE	dieldrin
Newman Wasteway	10	50	61	<4.0	<0.006	<0.001	0.003	<0.0002
Orestimba Creek at River Rd	9.6	315	290	6.5	0.018	0.012	0.091	0.002
Spanish Grant Drain	27	540	86	4.0	0.006	<0.001	0.046	0.002
Olive Avenue Drain	6 (est)	663	140	2.7	0.009	<0.001	0.093	0.0018
Del Puerto Creek at Vineyard Rd	7.8	90	160	7.6	0.003 (est)	<0.001	0.014	0.0007
Ingram Creek at River Rd	11	1,990	250	7.9	0.012	0.012	0.5	0.016
Hospital Creek at River Rd	32	2,530	310	7.6	0.027	0.013	0.78	0.019
San Joaquin River near Vernalis	1,110	142	150	2.5	<0.006	<0.001	0.021	0.0004

(est) estimated
Adapted from Kratzer (1999)

Table 9
Concentrations of p,p'-DDE and Dieldrin in Selected SJR Westside Tributaries During Stormwater Runoff Event (January 1995)

Site	Flow (cfs)	Suspended Sediment Concentration (mg/L)	On Suspended Sediment (µg/kg)		Dissolved in Water Column (µg/L)		Concentration in Water Column (µg/L)	
			p,p'-DDE	dieldrin	p,p'-DDE	dieldrin	p,p'-DDE	dieldrin
Newman Wasteway	14	419	150	<5.0	<0.01	<0.01	0.063	<0.0021
Orestimba Creek at River Rd	51	4,980	269	8.2	0.010	0.005 (est)	1.34	0.041
	26	3,100	290	7.0	0.009 (est)	<0.01	0.899	0.022
	300	--	200	5.5	<0.01	<0.01	--	--
	870	4,760	230	3.6	<0.01	0.006 (est)	1.09	0.017
	1,130	1,920	190	1.4	--	--	0.365	0.0027
	684	1,180	230	1.8	--	--	0.271	0.0021
Spanish Grant Drain	66	4,420	180	6.5	<0.01	<0.01	0.796	0.029
Olive Avenue Drain	31 (est)	2,990	160	2.0	0.009 (est)	<0.01	0.478	0.006
Del Puerto Creek at Vineyard Rd	1,000 (est)	10,500	36	0.5	<0.01	<0.01	0.378	0.005
Ingram Creek at River Rd	257 (est)	4,780	130	2.7	0.006 (est)	<0.01	0.621	0.013
Hospital Creek at River Rd	37 (est)	3,640	200	3.5	0.006 (est)	<0.01	0.728	0.013
San Joaquin River near Vernalis	2,940	511	97	<5.0	<0.01	<0.01	0.05	<0.0026

(est) estimated
Adapted from Kratzer (1999)

of these pesticides during the irrigation season. Kratzer (1998a) concludes that runoff from winter storms will continue to deliver a significant load of sediment-bound organochlorine pesticides to the San Joaquin River, even if the irrigation-induced sediment transport is reduced.

OCls in Bedded Sediments

The USGS, as part of the NAWQA program, in 1992 and 1995, collected bedded sediment samples in the San Joaquin and Sacramento River watersheds, respectively. The sediments were analyzed for TOC and for the suite of OCl pesticides (total DDT, dieldrin, total chlordane, and toxaphene) and total PCBs, as well as several other organochlorine and organophosphate pesticides and pyrethroid pesticides. The complete data set is included in Appendix D.

MacCoy and Domagalski (1999) reported on the USGS bedded sediment studies in the Sacramento River watershed. These 1995 studies analyzed streambed sediments in the Sacramento River basin for 31 organochlorine compounds. Nine were detected. The concentrations of DDD, DDE and DDT were detected in streambed sediments at all agricultural indicator sites (Jack Slough, East Canal and Colusa Basin Drain), and DDE was detected at three Sacramento River sites (Colusa, Verona and Freeport). Concentrations of o,p'-DDD (2.6 µg/kg) and p,p'-DDD (8.2 µg/kg) were detected at Jack Slough. p,p'-DDE values were detected at the Sacramento River sites at Colusa (3.5 µg/kg), Freeport (1.8 µg/kg), East Canal (1.5 µg/kg) and Colusa Basin Drain (5.4 µg/kg). At Jack Slough, p,p'-DDE was found at 12 µg/kg, and p,p'-DDT at 2.7 µg/kg. The detection of DDD, DDE and DDT at these sites was attributed to former agricultural use, since these compounds were not detected at sites with little or no upstream agriculture.

Organochlorine compounds were detected in streambed sediments of Arcade Creek, which is an urban stream in Sacramento, with p,p'-DDD at 4.9 µg/kg, and p,p'-DDE at 2.1 µg/kg. According to MacCoy and Domagalski (1999), the detection of DDD and DDE in the sediments of Arcade Creek can be attributed to past agricultural land use in the basin. They indicate that detection of DDD, DDE and DDT in Arcade Creek can be attributed to past household pest control.

Total DDT. The USGS detection limit for DDT isomers in sediments was either 1 or 2 µg/kg dry weight, depending on the isomer. Colusa Basin Drain, Sacramento River at Colusa, Sacramento River at Freeport, Cache Creek at Guinda, Bear River, Jack Slough, Tuolumne River at Modesto, Dry Creek in Modesto, Turlock Irrigation District Lateral #5, Mokelumne River at Woodbridge, Orestimba Creek, Spanish Grant Drain, Del Puerto Creek, Salt Slough, Mud Slough, San Joaquin River at Stevinson, San Joaquin River at Patterson, and San Joaquin River at Vernalis all had total DDT concentrations above the detection limit.

Dieldrin. The detection limit for dieldrin was 1 µg/kg dry weight. Arcade Creek, Orestimba Creek, Spanish Grant Drain, Del Puerto Creek and Salt Slough all had dieldrin concentrations above the detection limit.

Total Chlordane. The detection limits for cis- and trans-chlordane were 1 µg/kg dry weight. The only locations where sediments had total chlordane concentrations above the detection limit were Arcade Creek near Del Paso Heights in Sacramento and the Mokelumne River near Woodbridge.

Toxaphene. The detection limit for toxaphene was either 100 or 200 µg/kg dry weight. Sediment residues above the detection limit were only found at Orestimba Creek.

Total PCBs. The detection limit for PCBs was either 50 or 100 µg/kg dry weight. None of the locations sampled had PCB residues above the detection limit.

Interpretation of Sediment OCl Concentration Data. As discussed in another section of this report, there is no reliable way to evaluate the water quality significance of a sediment concentration for OCls or, for that matter, other constituents that are potential pollutants. The co-occurrence-based approach of Long and Morgan and MacDonald is not reliable for assessing the potential aquatic life toxicity to or bioaccumulation of the OCls by benthic and epibenthic organisms. Because of the strong binding of the OCls to particulate organic carbon, sediments with a high TOC would be expected to have elevated OCls without toxicity and bioaccumulation, compared to sediments with low TOC.

In general, those sediments with elevated concentrations of an OCl in the Sacramento River watershed had organic carbon in the range of 7 to 16 g/kg dry weight. The sediments of the westside tributaries of the San Joaquin River, which had one or more measurable OCls, had from about 6 to 9 g/kg TOC dry weight. The San Joaquin River sediment samples had a TOC from about 2 to about 7 g/kg dry weight. The concentrations of TOC found in the sediment samples by the USGS were low (from 0.1 to about 1 percent TOC) compared to those that are frequently found in aquatic sediments. This situation likely reflects the elevated inorganic erosional material present in the sediments. It is possible that the sediments with higher TOC content of a few percent had sufficient TOC to at least partially detoxify/immobilize the OCls and reduce their bioavailability for bioaccumulation in benthic organisms. In order to properly evaluate the bioavailability of OCls in the sediments of any of the sites sampled where measurable or unmeasurable OCls were investigated, it would be necessary to use the US EPA bioavailability testing with *Lumbriculus variegatus*. Further, to evaluate toxicity, the sediments should be tested with *Hyalella azteca*.

Future USGS NAWQA Studies. The USGS Sacramento office was contacted regarding the current round of NAWQA studies. Brown (pers. comm., 2002) stated that there is no followup on organochlorine organism tissue work being done. Dileanis (pers. comm., 2002) indicated that the only OCl water sample work being done during the current NAWQA studies is on Sacramento River at Freeport, Arcade Creek and Sacramento Slough. Also, San Joaquin River sampling is planned for winter 2002-2003. The sites were not identified. The data will be published at http://ca.water.usgs.gov/archive/waterdata.

Discussion of Recent OCl Organism Tissue Data

This section presents an overview discussion of the OCl fish and other aquatic organism recent (post-1997) data relative to exceedance of the OEHHA standard fish consumption screening values. As indicated, these values are based on a 21 g/day fish consumption rate, which translates to about 1 meal/week. They are based on an upper-bound cancer risk of one additional cancer in 100,000 people who consume fish at this rate over their lifetime. It is expected that there will be some individuals for some Central Valley Waterbodies who will consume fish from a listed Waterbody at a greater rate than the rate OEHHA used.

Table 10 presents a summary of all of the OCl aquatic organism tissue residue data that have been collected since 1997 compared to the OEHHA screening values. All data collected from 1997-2001 is, for the purposes of this report, termed "recent" data.

An "x" for an OCl and a location indicates that there are some recent OCl fish tissue or *Corbicula fluminea* data, where the concentrations of the OCl were above the OEHHA screening value. In situations where some fish had concentrations above the OEHHA screening value and others did not, an "x" was used to indicate that an exceedance of the value has recently occurred in at least one sampling of organisms at the location since 1997. An "o" means that there have been recent data collected with adequate analytical method sensitivity, which have shown that the concentrations of the OCl are below the OEHHA screening value. A "-" means that there have been no measurements made for this OCl at this location. A "?" indicates that the analytical methods used for the recent data have not had adequate sensitivity to determine the OCl at the OEHHA screening value. An "o?" indicates that the concentration of the OCl was just below the OEHHA screening value. An "x?" indicates that the concentration of the OCl in aquatic life tissue collected prior to 1997 was above the OEHHA screening value, but this OCl has not been measured at all, or with adequate sensitivity since 1997. An "*" indicates that organochlorine pesticides have been found in the water column at potentially significant concentrations; however, no data are available on the bioaccumulation of the OCls for this waterbody.

Based on past studies, the primary OCls of concern for excessive bioaccumulation in the Sacramento and San Joaquin River watersheds and the Delta are DDT, dieldrin, chlordane, toxaphene and PCBs. These are referred to herein as the primary OCls of concern.

Some of the past and recent studies have involved the use of analytical methods for certain of the OCls that did not have sufficient sensitivity to detect the OCl in fish tissue samples at the OEHHA screening values. Usually DDT and/or PCBs have been analyzed with sufficient sensitivity to detect exceedances. Unless previous studies showed exceedances of a certain OCl and there is no recent confirming data, the waterbody is not listed as a high priority for future studies.

Table 10
Summary of Central Valley Waterbodies with Excessive OCl Residues
Based on 1997 - 2000 Organism Tissue Data and OEHHA Screening Values

Location	Total DDT	Dieldrin	Total Chlordane	Total Toxaphene	Total PCBs
San Joaquin River Watershed					
San Joaquin River at Highway 99	o	o	o	o	o
San Joaquin River at Lander Avenue	o	x	o	o	o
Mud Slough	x	x	?	x	x
Salt Slough	x?	x?	?	x?	?
Merced River	x	x	o	x	x
San Joaquin River at Crow’s Landing	o	o	o	o	o
Orestimba Creek	x?	x?	?	x?	?
Spanish Grant Drain	x?	?	?	x?	x?
Olive Avenue Drain*	--	--	--	--	--
Turlock Irrigation District, Lateral #5	o	?	?	?	?
Del Puerto Creek	x?	?	?	?	?
Ingram Creek*	--	--	--	--	--
Hospital Creek*	--	--	--	--	--
Lower Tuolumne River	x	x	o	x	x
Stanislaus River	x	x?	?	x?	x
San Joaquin River at Vernalis	x	x	x	x	x
San Joaquin River “at Bowman Road”	x	?	o	?	x
San Joaquin River at Mossdale	x?	?	?	?	?
San Joaquin River “at Highway 4”	x	?	o	?	o
Sacramento River Watershed					
McCloud River	o	o	o	o	o
Clear Creek	o	o	o	o	o
Sacramento River at Keswick	o	?	o	--	x
Sacramento River at Bend Bridge, near Hamilton City	o	o	o	o	o
Mill Creek	o	o	o	o	o
Deer Creek	o	o	o	o	o
Big Chico Creek	o	o	o	o	o
Sacramento River at Colusa	o	?	o	--	x
Sutter Bypass	x?	x?	x?	x?	x?
Feather River near Nicolaus/Hwy 99	o	o	o	o	x
Feather River at Forbestown	--	--	--	--	x?
Yuba River	x?	?	?	?	?
East Canal near Nicolaus	x?	x?	?	?	?
Sacramento Slough	o	x	o	--	x
Colusa Basin Drain	x	x	x?	x?	o
Sacramento River at Veteran’s Bridge	o	?	o	--	x
Natomas East Main Drain	o	?	o	?	x

Table 10 (Cont.)

Sacramento River Watershed (Cont.)	**Total DDT**	**Dieldrin**	**Total Chlordane**	**Total Toxaphene**	**Total PCBs**
Arcade Creek	o	x?	x?	?	?
American River at Discovery Park	o	x	o	?	x
American River at Watt Avenue	x?	x?	x?	--	x?
American River at J Street	o	?	o	--	x
Sacramento River at Mile 44	x	x	o	--	x
Sacramento River at Hood	x	x	x	x	x
Cache Creek	o	?	?	?	o
Putah Creek	x	?	o	?	o?
Cache Slough	o	x	o	--	o
Sacramento River at Rio Vista	o	?	?	?	o
Delta					
Port of Stockton Turning Basin	x	?	o	?	x
Port of Stockton near Mormon Slough	o	x	?	?	x
Smith Canal	o	?	o	?	x
San Joaquin River around Turner Cut	o	?	o	?	o
White Slough downstream from Disappointment Slough	o	?	?	?	o
San Joaquin River at Potato Slough	o	?	o	?	x
San Joaquin River off Point Antioch	o	?	?	?	o
Sycamore Slough near Mokelumne River	o	x	?	?	?
Mokelumne River between Beaver and Hog Sloughs	o	?	?	?	o
Middle River at Bullfrog	o	?	?	?	o
Old River	x	?	o	?	x
Paradise Cut	x	?	o	?	o
Old River at Central Valley Pump	x	?	o	x	?
O'Neill Forebay/California Aqueduct	x?	?	x?	?	x?
Tulare Lake Basin					
King's River	o	?	o	?	o
Kern River	o?	?	?	?	--

x At least one fish sample taken in the late 1990s or 2000 was above the OEHHA screening value.
o None of the fish samples taken in the late 1990s or 2000 were above the OEHHA screening value.
? The analytical methods used were not sufficiently sensitive to measure the OCl at the OEHHA screening value.
o? The concentrations of an OCl were just below the OEHHA screening value.
x? The concentration of an OCl was above the screening value in the past but either has not been recently analyzed or the recent analytical methods used did not have sufficient sensitivity.
-- No measurements were made for this OCl.
* Organochlorine pesticides have been found in the water column at potentially significant concentrations. No data are available on the bioaccumulation of the OCls for this waterbody.

San Joaquin River Watershed. The uppermost point where fish have been recently collected and OCls have been measured with adequate sensitivity in the San Joaquin River watershed was at the San Joaquin River at Highway 99. The largemouth bass collected in 2000 did not show exceedances of the OEHHA screening value at this location for each of the primary OCls of concern. Further down the SJR at Lander Avenue, only dieldrin in white catfish collected in 1998 was above the OEHHA screening value. DDT, chlordane, toxaphene and PCBs were all below the OEHHA screening value.

Mud and Salt Sloughs are tributaries of the San Joaquin River that enter the River below Lander Avenue but above the Merced River. White catfish taken from Mud Slough in 1998 had concentrations of total DDT, dieldrin, toxaphene and total PCBs above OEHHA screening values. There have been no recent fish tissue data collected from Salt Slough. However, older data showed exceedances of total DDT, dieldrin and toxaphene.

Channel catfish and largemouth bass were collected from the Merced River at the Hatfield St. Recreation Area in 1998. These fish contained excessive concentrations of total DDT, dieldrin, chlordane, toxaphene and total PCBs above the OEHHA screening values. Future studies should include samples taken at several locations at and above the Hatfield St. Recreation Area.

The San Joaquin River at Crow's Landing receives the upstream discharges of Mud Slough, Salt Slough and the Merced River. The recent largemouth bass data collected at this location did not show exceedances for any of the OCls. It appears that Mud Slough, Salt Slough, and the Merced River, as well as the SJR at Lander Avenue, while having fish that show excessive OCls, are not contributing OCls to the San Joaquin River at sufficient concentrations to cause fish taken near Crow's Landing to have excessive OCls.

The westside tributaries to the SJR (Orestimba Creek, Spanish Grant Drain, Del Puerto Creek, Olive Avenue Drain, Ingram Creek and Hospital Creek) are major sources of OCls for the San Joaquin River. These waterbodies were found in the early 1990s to contain measurable concentrations of several of the OCls of concern in the water column that could bioaccumulate to excessive levels in aquatic organisms. There are no recent data on OCl concentrations in aquatic organisms taken from the westside tributaries. This is an area that should be a high priority for further study.

The mid- to lower eastside tributaries (Stanislaus River and Tuolumne River) of the San Joaquin River contain fish with excessive concentrations of several OCls. These tributaries are potentially contributing certain OCls to the San Joaquin River to cause fish taken from the San Joaquin River at Vernalis to show exceedances of the primary OCls of concern.

Fish taken recently from the San Joaquin River at Bowman Road and Highway 4 have had exceedances of one or more OCls. There has been no recent sampling of fish from the San Joaquin River at Mossdale. It would be expected, however, that they would also have an exceedance of total DDT.

Overall, with respect to the San Joaquin River watershed, the eastside and westside tributaries of the SJR contain fish with exceedances of one or more OCls. It also appears that these tributaries are discharging sufficient concentrations of some OCls to cause the fish taken from the San Joaquin River at Vernalis to contain excessive DDT, dieldrin, chlordane, toxaphene and PCBs.

Sacramento River Watershed. The Sacramento River and its tributaries above the Colusa Basin Drain (except at Keswick for PCBs), have been found, through recent fish collection, to have fish with OCls at less than the OEHHA screening value. While a 1997 sampling showed that there was an exceedence of PCBs in rainbow trout collected in the Sacramento River at Keswick, the subsequent samplings did not show this problem.

The Colusa Basin Drain is a main agricultural drain in the Central Sacramento Valley. Carp taken from the drain have been found to contain excessive DDT and dieldrin. White catfish did not contain excessive OCls. Previously, excessive chlordane and toxaphene have been found; however, there are no recently collected data with adequate sensitivity to ascertain the current situation with regard to toxaphene and chlordane in Colusa Basin Drain fish. The fish from this drain have recently been found to contain PCBs below the OEHHA screening value.

The recent white catfish and largemouth bass samplings from the Feather River near Nicolaus/Highway 99 have shown no exceedances of organochlorine pesticides. However, PCBs were found in pike minnow from the Feather River near Nicolaus/Highway 99 in excess of the OEHHA screening value.

In 1980, a variety of types of fish from the Feather River at Forbestown did show exceedances of PCBs. These exceedances relate to the use of PCB oils for road dust control. There has been no followup on this situation. It is suggested that this should be followed up to determine the current situation.

White catfish taken from the Sacramento Slough in 2000 contained excessive dieldrin and PCBs. Largemouth bass did not have excessive dieldrin, but did have excessive PCBs. DDT and chlordane were less than OEHHA screening values.

Sacramento River at Veteran's Bridge had excessive PCBs in white catfish.

Natomas East Main Drain white catfish and largemouth bass contained excessive PCBs.

Recently sampled largemouth bass from the American River had exceedances of PCBs, while excessive dieldrin was found in pike minnow.

Sacramento River at Mile 44 had excessive DDT, dieldrin and PCBs in white catfish and excessive DDT and PCBs in largemouth bass.

Sacramento River at Hood had white catfish and largemouth bass showing exceedances of all of the primary OCls of concern.

Excessive DDT was found in largemouth bass obtained from Putah Creek.

Largemouth bass from Cache Slough had exceedances of dieldrin.

Delta. The Port of Stockton Turning Basin had excessive PCBs and DDT in largemouth bass.

Dieldrin and PCBs were found in *Corbicula fluminea* sampled from the Port of Stockton near Mormon Slough.

Largemouth bass and white catfish taken from the Smith Canal at Yosemite Lake contained excessive PCBs.

The San Joaquin River below Turner Cut and the Central Delta have not recently been found to contain excessive OCls (DDT and PCBs) in fish.

Sycamore Slough near Mokelumne River had an exceedance of dieldrin found in largemouth bass.

White catfish taken from Old River at several locations have been found to contain excessive DDT and, at one location, PCBs. Excessive DDT in largemouth bass from Paradise Cut were found.

Tulare Lake Basin. No problems were encountered with excessive OCls in recently sampled King's River fish.

Recommended Approach for Establishing the OCl Management Program

Lee and Jones-Lee (2001) have discussed a recommended approach for developing management programs for organochlorine pesticides and PCBs. The recommended approach for establishing the legacy pesticide, PCB and dioxin/furan excessive bioaccumulation management program is to first obtain sufficient funding so that a comprehensive study can be conducted on current OCl concentrations in edible fish from the listed Waterbodies. Particular attention should be given to sampling from various locations within the Waterbodies to see if there are areas where fish and other organisms (such as clams) have higher concentrations. The NAWQA studies of the USGS indicate that *Corbicula fluminea* is present in many waterbodies in the Central Valley and that it shows a tendency to bioaccumulate OCls. While it may not be possible to use *Corbicula fluminea* tissue residues to evaluate the health threats of OCl bioaccumulation through the consumption of fish, *Corbicula fluminea* could be a suitable organism for detecting "hot spots" of OCls present in the sediments.

At the same time that sampling is conducted for fish and *Corbicula fluminea*, samples of sediment from various locations in the listed Waterbodies should also be taken and analyzed for OCls of concern. It would be highly desirable, although it may not be possible during the initial study, to do the sediment bioaccumulation evaluation using *Lumbriculus variegatus* (the oligochaete), following procedures similar to those used in the Smith Canal sediment PCB study (Lee, *et al.*, 2002).

For each of the listed Waterbodies an advisory panel should be appointed to plan, implement and report on the needed studies. Suggested members of this panel include the CVRWQCB staff, DPR staff, county agriculture commissioners, CALFED, agricultural interests, Farm Bureau, county RCDs, irrigation districts, Department of Fish and Game and environmental groups. The results of this monitoring program could take several years to establish current degrees of excessive bioaccumulation for the OCls. This approach would also provide information that is needed to develop a site-specific sediment biota accumulation factor for each listed Waterbody or parts thereof.

For some of the listed Waterbodies - possibly most - there would be need to determine the external loads of OCls associated with summer irrigation season tailwater discharges and winter stormwater runoff. If substantial loads are found of excessive bioaccumulation at the point where the tributary discharges to the Waterbody, then forensic studies would need to be conducted to determine the origin of these loads within the Waterbody's watershed.

Ultimately, from studies of this type, it should be possible to determine whether current external loads of OCls represent a significant source of OCls that are bioaccumulating to excessive levels. This information could then be used to determine whether there is need to establish a control program from watershed sources of OCls for Waterbodies that currently have excessive bioaccumulation of one or more OCls in one or more types of fish.

A list of specific areas of further study for OCl bioaccumulation management program development includes the following:

- Determine, for each of the listed Waterbodies, as well as other Central Valley waterbodies, the current degree of edible fish tissue OCl residues. These residues should be compared to OEHHA screening values which have been adjusted for local fish consumption rates. This information is essential to defining the waterbodies within the Central Valley where OCls have bioaccumulated to excessive levels in edible fish.
- Determine for each of the listed Waterbodies whether stormwater runoff and/or irrigation tailwater discharges and/or domestic and industrial wastewater discharges are currently contributing sufficient concentrations of the OCl of concern in the Waterbody to be contributing to the excessive bioaccumulation of this OCl(s) in edible fish tissue.

- Conduct a quantitative assessment of the current atmospheric loads of the OCls for several of the listed Waterbodies to evaluate the potential significance of this source.
- Determine the concentrations of the OCls of concern in the listed Waterbodies and the bioavailability of the sediment-associated OCl residues for food web accumulation that leads to excessive edible tissue residues.
- Determine the extent of edible fish tissue contamination by dioxins and furans within the Central Valley Waterbodies. Where excessive concentrations are found in edible fish tissue, determine likely sources of the dioxins and furans that are bioaccumulating to excessive levels.
- Since the allowable OCl tissue residue for edible fish is dependent on local waterbody fish consumption rates, it is recommended that, as part of developing the management program for the OCl-listed Waterbodies, representative fish consumption rates for each listed Waterbody be developed.
- It is recommended that studies of the type conducted by USGS NAWQA in the early to mid-1990s be conducted again to verify that the continued transport of several organochlorine pesticides from agricultural and urban areas at potentially significant concentrations is occurring.
- There is need for studies to determine for each OCl-listed Waterbody whether current transport of the OCls to the Waterbody significantly contributes to the bioavailable OCl residues within the Waterbody that lead to excessive bioaccumulation in edible organism tissue.
- Special-purpose studies need to be conducted using aquatic organism incubation to determine if domestic wastewaters are a significant source of OCls for certain Central Valley Waterbodies.
- Studies should be conducted to determine if the bioaccumulation by the freshwater clam *Corbicula fluminea* could be used to evaluate the bioaccumulation that may be occurring in edible fish.
- All fish tissue analyses for the OCls should be conducted with an analytical method detection limit that is at least slightly below the OEHHA human health screening value.
- The fish samples that are currently stored frozen, taken from Smith Canal and a number of other locations, should be analyzed for OCl content in edible tissue.
- It is recommended that systematic studies of fish tissue OCl concentrations for the fish types of concern at a particular location be conducted to examine the variability in OCl composition at about the same time and location. This information is essential to understanding whether the apparent changes in OCl composition over time are related to real changes or simply reflect the variability of the data.
- It is also recommended that all OCl measurements of fish tissue include measurements of the lipid content. This information may be useful to normalize the OCl bioaccumulation based on fish edible tissue lipid content.

High Priority Areas for Further Fish Collection and OCl Analyses. At each of the locations listed below, at least one and possibly several types of edible fish, such as white catfish, largemouth bass and channel catfish, and, if necessary, carp should be collected and analyzed for the suite of OCls, using analytical methods that have adequate sensitivity to detect exceedances of the OEHHA screening values shown in Table 11.

Table 11
OEHHA Human Health Fish Screening Values and DFG Analytical Method Reporting Limits for Primary OCls of Concern

OCl	OEHHA Screening Value (µg/kg wet weight)	Dept. of Fish & Game Proposed Reporting Limit (µg/kg wet weight)*
Total DDT	100	2 to 5, for DDT isomers
Dieldrin	2	0.5
Total Chlordane	30	1 for cis- and trans-chlordane
Total Toxaphene	30	20
Total PCBs	20	Aroclors 10-25

*Information provided by D. Crane, (pers. comm.) CA DFG, 2002.

Suggested Locations for High Priority Future Fish Collection and OCl Analysis

San Joaquin River at Lander Avenue
Mud Slough
Salt Slough
Merced River
Orestimba Creek, Spanish Grant Drain, Del Puerto Creek, Olive Avenue Drain, Ingram Creek and Hospital Creek
Stanislaus River and Tuolumne River
San Joaquin River at Vernalis
San Joaquin River at Highway 4
Colusa Basin Drain
Sutter Bypass
Feather River at Forbestown
Feather River at Nicolaus
Yuba River
East Canal near Nicolaus
Sacramento River at Veteran's Bridge
Sacramento Slough
Natomas East Main Drain
American River at several locations
Sacramento River at Mile 44
Sacramento River at Hood
Putah Creek
Cache Slough
Port of Stockton Turning Basin
Port of Stockton near Mormon Slough
Smith Canal at Yosemite Lake
Sycamore Slough near Mokelumne River
Old River at several locations

Paradise Cut

Adequate Analytical Method Sensitivity. D. Crane (pers. comm., 2002) of the California Department of Fish and Game (CA DFG) has recently provided information on the Department of Fish and Game's current laboratory capabilities for measurement of the OCls. As shown in Table 11, CA DFG laboratory currently has the ability to measure the OCls of concern with adequate detection limits (reporting limits) to screen fish for exceedances of OEHHA screening values.

Use of Clams. One of the issues that should be considered is the appropriateness of collecting *Corbicula fluminea* (fresh water clam) as part of evaluating whether there are exceedances of the OEHHA screening values. According to C. Foe (pers. comm., 2002), *Corbicula* is used within the Central Valley as human food. Therefore, there is justification for sampling *Corbicula* to determine if it contains excessive OCls. This sampling, however, should not be a substitute for the collection and analysis of game fish such as white catfish and largemouth bass, which are more widely consumed by humans than *Corbicula*. It is suggested that the focus of the sampling should be on the types of fish and other organisms that are used in a region as food.

References

Ahmed, F. E., Ed. 1991. Seafood Safety. Committee on Evaluation of the Safety of Fishery Products, Food and Nutrition Board, Institute of Medicine. National Academy Press: Washington, D.C.

APHA, AWWA, and WEF. 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Water Works Association, Water Environment Federation, 20th Edition, Washington, DC.

Bailey, G. W. and White, J. L. 1964. "Review of Adsorption and Desorption of Organic Pesticides by Soil Colloids, with Implications Concerning Pesticide Bioactivity." *J. Agric. Food Chem.* 12:324-332.

Bailey, G. W. and White, J. L. 1970. "Factors Influencing the Adsorption, Desorption, and Movement of Pesticides in Soils." *Residue Rev.* 32:29-92.

Barber, M. C.; Galvin, M.; Daniel, B.; Phillips, L.; Weinrich, K.; and Rowell, A. 2002. "BASS Graphical User Interface (GUI) beta test version 1.0 for BASS version 2.1." US Environmental Protection Agency, Ecosystems Research Division, Athens, GA. For the latest version, contact barber.craig@epa.gov, (706)355-8110.

Boese, B. L. and H. Lee II. 1992. "Synthesis of Methods to Predict Bioaccumulation of Sediment Pollutants." ERL-N No. N232. U.S. Environmental Protection Agency, Environmental Research Laboratory, Narragansett, RI.

Bridges, T. S.; Moore, D. W.; Landrum, P.; Neff, J.; and Cura, J. 1996. "Summary of a Workshop on Interpreting Bioaccumulation Data Collected During Regulatory Evaluations of Dredged Material." Misc. Paper D-96-1, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Brodberg, R. K. and Pollock, G. A. 1999. "Prevalence of Selected Target Chemical Contaminants in Sport Fish from Two California Lakes: Public Health Designed Screening Study, Final Project Report." EPA Assistance Agreement No. CX 825856-01-0, Pesticide and Environmental Toxicology Section, Office of Environmental Health Hazard Assessment, Sacramento, CA.

Broman, D., Naf, C.; Rolff, C.; Zebuhr, Y.; Fry, B.; and Hobbie, J. 1992. "Using Ratios of Stable Nitrogen Isotopes to Estimate Bioaccumulation and Flux of Polychlorinated Dibenzo-*p*-dioxins (PCDDs) and Dibenzofurans (PCDFs) in Two Food Chains from the Northern Baltic." *Environ. Toxicol. Chem.* 11:331-345.

Brower, J. and Cecchine, G. 2002. "Bioavailability in Sediments." In: Whittemore, *et al.* (eds.) Handbook on Sediment Quality, Special Publication, Water Environment Federation, Alexandria, VA, pp. 99-137.

Brown, L. R. 1997. "Concentrations of Chlorinated Organic Compounds in Biota and Bed Sediment in Streams of the San Joaquin Valley, California." *Archives of the Environmental Contamination and Toxicology* 33(4):357-368.

Brown, L. R. 1998. "Concentrations of Chlorinated Organic Compounds in Biota and Bed Sediment in Streams of the Lower San Joaquin River Drainage, California." U. S. Geological Survey, Open-File Report 98-171, Sacramento, CA.

Buchman, M. 1999. "Screening Quick Reference Tables (SQuiRTs)." Coastal Protection & Restoration Division (CPR), National Oceanic and Atmospheric Administration (NOAA), Seattle, WA.

Burton, G. A., Jr. 2002. "Summary of Pellston Workshop on Use of Sediment Quality Guidelines (SQGs) and Related Tools for the Assessment of Contaminated Sediments." Proceedings of Sediment Quality Assessment (SQA5), Aquatic Ecosystem Health and Management Society, Chicago, IL.

Chapman, P. M. 2002. "Modifying Paracelsus' Dictum for Sediment Quality Assessments." Proceedings of Sediment Quality Assessment (SQA5), Aquatic Ecosystem Health and Management Society, Chicago, IL.

Cheng, H. H. 1990. Pesticides in the Soil Environment: Processes, Impacts, and Modeling. Soil Science Society of America, Madison, WI.

Chiou, C. T. 2002. Partition and Adsorption of Organic Contaminants in Environmental Systems. Wiley: New York, NY.

Chiou, C. T.; Freed, V.; Schmedding, D.; and Kohnert, R. 1977. "Partition Coefficient and Bioaccumulation of Selected Organic Chemicals." *Environmental Science and Technology* 11(5):475-478.

Cook, P. M.; Erickson, R. J.; Spehar, R. L.; Bradbury, S. P.; and Ankley, G. T. 1993. "Interim Report on Data and Methods for Assessment of 2,3,7,8-Tetrachlorodibenzo-p-dioxin: Risks to Aquatic Life and Associated Wildlife." EPA/600/R-93/055. US Environmental Protection Agency, Environmental Research Laboratory, Duluth, MN.

Cooke, J. and Karkoski, J. 2001. "Clear Lake TMDL for Mercury Numeric Target Report." California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA, June.

CVRWQCB. 1998. The Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board, Central Valley Region — The Sacramento River Basin and The San Joaquin River Basin. Fourth Edition.

CVRWQCB. 2000. Final Staff Report on Recommended Changes to California's Clean Water Act Section 303(d) List. http://www.swrcb.ca.gov/rwqcb5/programs/tmdl/303dupdate.pdf

CVRWQCB. 2002. Petition for Review of Waste Discharge Requirements, Order No. R5-2002-0083 (NPDES No. CA0079138) and Cease and Desist Order No. R5-2002-0084, City of Stockton, Regional Wastewater Control Facility, San Joaquin County. Central Valley Regional Water Quality Control Board, Sacramento, CA, August 30.

Davis, J. A. 2000. Chlorinated Hydrocarbons in the San Francisco Estuary and its Watershed. Draft Chapter xx in Spies, R. B. (ed.). Contaminants and Toxicity in the Sacramento-San Joaquin Delta, Its Catchment, and the San Francisco Estuary – A CALFED White Paper. Applied Marine Sciences, Livermore, CA.

Davis, J.; May, M.; Ichikawa, G.; and Crane, D. 2000. "Contaminant Concentrations in Fish from the Sacramento—San Joaquin Delta and Lower San Joaquin River, 1998." San Francisco Estuary Institute, Richmond, CA.

DHS. 1997a. Health Consultation: McCormick & Baxter Creosoting Company, Stockton, San Joaquin County, California, CERCLIS No. CAD009106527, January 15, 1997. California Department of Health Services, Berkeley, CA.

DHS. 1997b. Health Consultation: McCormick & Baxter Creosoting Company, Stockton, San Joaquin County, California, CERCLIS No. CAD009106527, April 9, 1997. California Department of Health Services, Berkeley, CA.

Dileanis, P.; Sorenson, S.; Schwarzbach, S.; Maurer, T. 1992. Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Sacramento National Wildlife Refuge Complex, California, 1988-89. US Geological Survey Water Resources Investigations Report 92-4036, USGS, Sacramento, CA.

DiToro, D. 2002. " Sediment Toxicity Prediction – What is Known and Unknown." Proceedings of Sediment Quality Assessment (SQA5), Aquatic Ecosystem Health and Management Society, Chicago, IL (in press).

DiToro, D. M.; Zarba, C. S.; Hansen, D. J.; Berry, W. J.; Swartz, R. C.; Cowan, C. E.; Pavlou, S. P.; Allen, H. E.; Thomas, N. A.; and Paquin, P. R. 1991. "Technical Basis for Establishing Sediment Quality Criteria for Nonionic Organic Chemicals by Using Equilibrium Partitioning." *Environ. Toxicol. Chem*. 10:1541-1583.

Domagalski, J. L. 1997. "Pesticides in Surface and Ground Water of the San Joaquin-Tulare Basins, California: Analysis of Available Data, 1966 through 1992." U. S. Geological Survey, Water-Supply Paper 2468, Washington, D.C.

Domagalski, J. L. 2000. "Pesticides in Surface Water Measured at Select Sites in the Sacramento River Basin, California, 1996-1998." U. S. Geological Survey, Water-Resources Investigations Report 00-4203, Sacramento, CA.

Domagalski, J. L. and Dileanis, P. D. 2000. "Water-Quality Assessment of the Sacramento River Basin, California - Water Quality of Fixed Sites, 1996-1998." U. S. Geological Survey, Water-Resources Investigations Report 00-4247, Sacramento, CA.

Domagalski, J. L.; Knifong, D. L.; Dileanis, P. D.; Brown, L. R.; May, J. T.; Connor, V.; and Alpers, C. N. 2000. "Water Quality in the Sacramento River Basin, California, 1994-98." U. S. Geological Survey Circular 1215, Sacramento, CA.

Dubrovsky, N. M.; Kratzer, C. R.; Brown, L. R.; Gronberg, J. M.; and Burow, K. R. 1998. "Water Quality in the San Joaquin-Tulare Basins, California, 1992-95." US Geological Survey Circular 1159, Sacramento, CA.

Eisler, R. 1989. "Tin Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review." Biological Report 85(1.15). Contaminant Hazard Reviews, Fish and Wildlife Service, U.S. Department of the Interior, Washington, DC.

Fisher, T.; Hayward, D.; Stephens, R.; and Stenstrom, M. 1999. "Dioxins and Furans in Urban Runoff." *Journ. Environ. Engr*. 125(2):185-191.

Foe, C. 2002. Recent TSMP Data (Preliminary). Central Valley Regional Water Quality Control Board, Sacramento, CA.

Gobas, F. A. P. C. 1993. "A Model for Predicting the Bioaccumulation of Hydrophobic Organic Chemicals in Aquatic Food Webs: Application to Lake Ontario." *Ecol. Model.* 69:1-17.

Gronberg, J.; Dubrovsky, N.; Kratzer, C.; Domagalski, J.; Brown, L.; Burow, K. 1998. "Environmental Setting of the San Joaquin—Tulare Basins, California," USGS Water Resources Investigations Report 97-4205, US GS, Sacramento, CA.

Harnly, M.; Seidel, S.; Rojas, P.; Fornes, R.; Flessel, P.; Smith, D.; Kreutzer, R.; and Goldman, L. 1997. "Biological Monitoring for Mercury Within a Community with Soil and Fish Contamination." *Environmental Health Perspectives* 105(4): 424-429.

Harte, J.; Holdren, C.; Schneider, R.; Shirley, C. 1991. "Toxics A to Z: A Guide to Everyday Pollution Hazards." University of California Press, Berkeley, CA.

HydroQual, Inc. 1995. "Bioaccumulation of Superlipophilic Organic Chemicals: Data Compilation and Analysis." Prepared for Abt Associates, Bethesda, MD, for U.S. Environmental Protection Agency.

Jarvinen, A. W. and Ankley, G. T. 1999. Linkage of Effects to Tissue Residues: Development of a Comprehensive Database for Aquatic Organisms Exposed to Inorganic and Organic Chemicals. Society for Environmental Toxicology and Chemistry. SETAC Press: Pensacola, FL.

Jones, R. A. and Lee, G. F. 1978. "Evaluation of the Elutriate Test as a Method of Predicting Contaminant Release during Open Water Disposal of Dredged Sediment and Environmental Impact of Open Water Dredged Materials Disposal, Vol. I: Discussion." Technical Report D-78-45, US Army Engineer Waterways Experiment Station, Vicksburg, MS. August.

Jones-Lee, A. and Lee, G. F. 1998. "Evaluation Monitoring as an Alternative to Conventional Water Quality Monitoring for Water Quality Characterization/ Management." Proc. of the NWQMC National Conference "Monitoring: Critical Foundations to Protect Our Waters," US Environmental Protection Agency, Washington, D.C., pp. 499-512.

Kilduff, J.; LeBoeuf, E.; Nyman, M. 2002. "Sorption of Organic Compounds by Soils and Sediments: Equilibrium and Rate Processes." In: Whittemore, *et al.* (eds.) Handbook on Sediment Quality, Special Publication, Water Environment Federation, Alexandria, VA, pp. 7-98.

Kratzer, C. R. 1998a. "Transport of Sediment-Bound Organochlorine Pesticides to the San Joaquin River, California." U. S. Geological Survey, Open-File Report 97-655, Sacramento, CA.

Kratzer, C. R. 1998b. "Pesticides in Storm Runoff from Agricultural and Urban Areas in the Tuolumne River Basin in the Vicinity of Modesto, California." U. S. Geological Survey, Water-Resources Investigations Report 98-4017, Sacramento, CA.

Kratzer, C. R. 1999. "Transport of Sediment-Bound Organochlorine Pesticides to the San Joaquin River, California." *J. American Water Resources Association*. 35(4):957-981

Lake, J. L.; Rubinstein, N. I.; Lee II, H.; Lake, C. A.; Heltshe, J.; and Pavignano, S. 1990. "Equilibrium Partitioning and Bioaccumulation of Sediment-Associated Contaminants by Infaunal Organisms." *Environ. Toxicol. Chem*. 9:1095-1106.

Larson, S. J.; Capel, P. D.; and Majewski, M. S. 1997. Pesticides in Surface Water: Distribution, Trends and Governing Factors. Pesticides in Hydrologic System Series, Vol. 3. Ann Arbor Press: Chelsea, Michigan.

Lee, H. II. 1991. "Models, Muddles, and Mud: Predicting Bioaccumulation of Sediment-Associated Pollutants. In: G. A. Burton, Jr. (ed.) *Sediment Toxicity Assessment*. Lewis Publishers, Boca Raton, FL, pp. 267-289.

Lee, G. F. and Jones, R. A. 1992. "Sediment Quality Criteria Development: Technical Difficulties with Current Approaches and Suggested Alternatives." Condensed version published as Lee, G. F., and Jones, R. A., "Sediment Quality Criteria Development: Technical Difficulties with Current Approaches (Condensed Version)," in: Proc. HMCRI R&D 92 Conference on the Control of Hazardous Materials, HMCRI, Greenbelt, MD, pp. 204-211.

Lee, G. F. and Jones-Lee, A. 1993. "Sediment Quality Criteria: Numeric Chemical- vs. Biological Effects-Based Approaches." Proc. Water Environment Federation National Conference, Surface Water Quality & Ecology, pp. 389-400.

Lee, G. F. and Jones-Lee, A. 1996a. "'Co-Occurrence' in Sediment Quality Assessment." G. Fred Lee & Associates, El Macero, CA.

Lee, G. F. and Jones-Lee, A. 1996b. "Evaluation of the Water Quality Significance of the Chemical Constituents in Aquatic Sediments: Coupling Sediment Quality Evaluation Results to Significant Water Quality Impacts." In: WEFTEC '96, Surface Water Quality and Ecology I & II, Vol 4, pp 317-328, Proc. Water Environ. Fed. Annual Conference.

Lee, G. F. and Jones-Lee, A. 2000. "Water Quality Aspects of Dredging and Dredged Sediment Disposal." In: Handbook of Dredging Engineering, Second Edition, McGraw Hill, pp. 14-1 to 14-42.

Lee, G. F. and Jones-Lee, A. 2001. "Developing TMDLs for Organochlorine Pesticides and PCBs." Environmental Chemistry Division Extended Abstracts, American Chemical Society national meeting, San Diego, California, April.

Lee, G. F. and Jones-Lee, A. 2002. "Appropriate Incorporation of Chemical Information in a Best Professional Judgment Triad Weight of Evidence Evaluation of Sediment Quality." Proceedings of Sediment Quality Assessment (SQA5), Aquatic Ecosystem Health and Management Society, Chicago, IL.

Lee, G. F.; Jones-Lee, A.; and Ogle, R. S. 2002. "Preliminary Assessment of the Bioaccumulation of PCBs and Organochlorine Pesticides in *Lumbriculus variegatus* from City of Stockton Smith Canal Sediments, and Toxicity of City of Stockton Smith Canal Sediments to *Hyalella azteca*." Report to the DeltaKeeper and the Central Valley Regional Water Quality Control Board, G. Fred Lee & Associates, El Macero, CA, July.

Lee, G. F.; Jones, R. A.; Saleh, F. Y.; Mariani, G. M.; Homer, D. H.; Butler, J. S.; and Bandyopadhyay, P. 1978. "Evaluation of the Elutriate Test as a Method of Predicting Contaminant Release during Open Water Disposal of Dredged Sediment and Environmental Impact of Open Water Dredged Materials Disposal, Vol. II: Data Report," Technical Report D-78-45, US Army Engineer Waterways Experiment Station, Vicksburg, MS, 1186 pp., August.

Lee II, H. 1992. "Models, Muddles, and Mud: Predicting Bioaccumulation of Sediment Associated Pollutants." In: *Sediment Toxicity Assessment*, ed. G.A. Burton, Jr., pp. 267-293. Lewis Publishers: Boca Raton, FL.

Long, E., and Morgan, L. 1990. "The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program." NOAA Technical Memorandum NOS OMA 52, National Oceanic and Atmospheric Administration, Seattle, WA.

LWA. 2002. "Sacramento River Watershed Program Annual Monitoring Report: 2000-2001." Report to Sacramento River Watershed Program, Larry Walker Associates, Davis, CA.

MacCoy, D. E. and Domagalski, J. L. 1999. "Trace Elements and Organic Compounds in Streambed Sediment and Aquatic Biota from the Sacramento River Basin, California, October and November 1995." U. S. Geological Survey, Water-Resources Investigations Report 99-4151, Sacramento, CA.

MacDonald, D. 1992. "Development of an Approach to the Assessment of Sediment Quality in Florida Coastal Waters." Report submitted to the Florida Department of Environmental Regulation, Tallahassee, FL.

McFarland, V. A. and Ferguson, P. W. 1994. "TBP revisited: A Ten-Year Perspective on a Screening Test for Dredged Sediment Bioaccumulation Potential." *Proceedings, Dredging '94*, pp. 718-727, November 13-16, 1994, Lake Buena Vista, Florida. American Society of Civil Engineers, New York, NY.

Mischke, T.; Brunetti, K.; Acosta, V.; Weaver, D.; and Brown, M. 1985. "Agricultural Sources of DDT Residues in California's Environment." Report Prepared in Response to House Resolution No. 53 (1984). California Department of Food and Agriculture, Sacramento, CA.
Available from http://www.cdpr.ca.gov/docs/ipminov/ddt/ddt.htm

NAS/NAE. 1973. Water Quality Criteria 1972. National Academy of Sciences, National Academy of Engineering, US Environmental Protection Agency R3 73 033, Washington, DC.

Norberg-King, T. 2002. "California Sediment Samples." Memorandum to Peter Kozelka, US Environmental Protection Agency, National Health and Environmental Effects Research Laboratory Mid-Continent Ecology Division, Duluth, MN, June 10.

O'Connor, T. P. 1999a. "Sediment Quality Guidelines Do Not Guide." NOAA National Status and Trends Program, *SETAC News*, Learned Discourses: Timely Scientific Opinions, January.

O'Connor, T. P. 1999b. "Sediment Quality Guidelines Reply-to-Reply." NOAA National Status and Trends Program, *SETAC News*, Learned Discourses: Timely Scientific Opinions, May.

O'Connor, T. P. 2002. "Empirical and Theoretical Shortcomings of Sediment-Quality Guidelines." In: Whittemore, *et al.* (eds.) Handbook on Sediment Quality, Special Publication, Water Environment Federation, Alexandria, VA, pp. 317-325

O'Connor, T. P. and Paul, J. F. 2000. "Misfit between Sediment Toxicity and Chemistry." *Mar. Poll.Bull.* 40:59-64.

O'Connor, T. P.; Daskalakis, K. D.; Hyland, J. L.; Paul, J. F.; and Summers, J. K. 1998. "Comparisons of Measured Sediment Toxicity with Predictions based on Chemical Guidelines." *Environ. Toxicol. Chem.* 17:468-471.

OEHHA. 1999. "Prevalence of Selected Target Chemical Contaminants in Sport Fish from Two California Lakes: Public Health Designed Screening Study." Office of

Environmental Health Hazard Assessment, California Environmental Protection Agency, Sacramento, CA.

OEHHA. 2002. "Drinking Water MCLs." Office of Environmental Health Hazard Assessment, Sacramento, CA. www.oehha.ca.gov/water

Panshin, S. Y.; Dubrovsky, N. M.; Gronberg, J. M.; and Domagalski, J. L. 1998. "Occurrence and Distribution of Dissolved Pesticides in the San Joaquin River Basin, California." US Geological Survey, Water-Resources Investigations Report 98-4032, Sacramento, CA.

Parkerton, T. F.; Connolly, J. P.; Thomann, R. V.; and Uchrin, C. G. 1993. "Do Aquatic Effects or Human Health End Points Govern the Development of Sediment-Quality Criteria for Nonionic Organic Chemicals?" *Environ. Toxicol. & Chem.* 12:507-523.

Pereira, W.; Domagalski, J.; Hostettler, F.; Brown, L.; and Rapp, J. 1996. "Occurrence and Accumulation of Pesticides and Organic Contaminants in River Sediment, Water and Clam Tissues from the San Joaquin River and Tributaries, California." *Environ. Tox. & Chem.* 15(2):172-180.

Peterson, B. J. and Fry, B. 1987. "Stable Isotopes in Ecosystem Studies." *Ann. Rev. Ecol. Syst.* 18:293-320.

PTI. 1995. "Analysis of BSAF Values for Nonpolar Organic Compounds in Finfish and Shellfish." PTI Environmental Services, Final Report Prepared for Washington State Department of Ecology, Olympia, WA.

Rasmussen, D. 1993. "Toxic Substances Monitoring Program 1991 Data Report," Report 93-1WQ, State Water Resources Control Board, California Environmental Protection Agency, Sacramento, CA.

Rasmussen, D. 1997. "Toxic Substances Monitoring Program 1994-95 Data Report," State Water Resources Control Board, California Environmental Protection Agency, Sacramento, CA.

Ross, L.; Stein, R.; Hsu, J.; White, J.; and Hefner, K. 1999. "Distribution and Mass Loading of Insecticides in the San Joaquin River California, Spring 1991 and 1992." Report EH99-01/April 1999. Environmental Hazardous Assessment Program, Environmental Monitoring and Pest Management Branch, California Department of Pesticide Regulations, Sacramento, CA.

SARWQCB. 2000. "Problem Statement for the Total Maximum Daily Load for Toxic Substances in Newport Bay and San Diego Creek, Final." Santa Ana Regional Water Quality Control Board, Riverside, CA, December.

SFBRWQCB. 1997. "Survey of Storm Water Runoff for Dioxins in the San Francisco Bay Area." Report prepared by California Regional Water Quality Control Board, San Francisco Bay Region, San Francisco, CA, February.

SFEI. 2001. "Contaminant Concentrations in Fish from the Sacramento-San Joaquin Delta and Lower San Joaquin River." San Francisco Estuary Institute, Richmond, California. Available from www.sfei.org.

SFEI. 2002. "PCBs in the Bay." EcoAtlas Information System, San Francisco Estuary Institute, Richmond, CA. http://ecoatlas.org/custom/pcbtool.html

Spacie, A.; McCarty, L. S.; and Rand, G. M.. 1995. "Bioaccumulation and Bioavailability in Multiphase Systems." In: Fundamentals of Aquatic Toxicity: Effects, Environmental Fate, and Risk Assessment, 2nd ed., ed. G. M. Rand, pp. 493-521. Taylor & Francis: Washington, DC.

SWRCB. 1998a. "California Ocean Plan." Draft Functional Equivalent Document, Amendment of the Water Quality Control Plan for Ocean Waters of California. State Water Resources Control Board, Division of Water Quality, Sacramento, CA, October.

SWRCB. 1998b. "303(d) Listing of Impaired Waterbodies." California Water Resources Control Board, Sacramento, CA.
http://www.swrcb.ca.gov/tmdl/303d_lists.html

SWRCB/TSMP. 2002. "Toxic Substances Monitoring Program." Water Resources Control Board, Toxic Substances Monitoring Program, databases and annual reports, Sacramento, CA. http://www.swrcb.ca.gov/programs/smw/index.html

Thomann, R. V. 1989. "Bioaccumulation Model of Organic Distribution in Aquatic Food Chains." *Environ. Sci. Technol.* 23:699-707.

Tracey, G. A. and Hansen, D. J. 1996. "Use of Biota-Sediment Accumulation Factors to Assess Similarity of Nonionic Organic Chemical Exposure to Benthically-Coupled Organisms of Differing Trophic Mode." *Arch. Environ. Contam. Toxicol.* 30:467-475.

US ACOE. 1997. "The Environmental Residue-Effects Database (ERED)." Home Page <http://www.wes.army.mil/el/ered/index.html> U.S. Army Corps of Engineers, webdate: November 4.

US EPA. 1979. Water-Related Environmental Fate of 129 Priority Pollutants, Volumes 1 and 2, EPA-440/4-79-029a,b. U.S. Environmental Protection Agency, Office of Water Planning and Standards (WH-553), Washington, D.C.

US EPA. 1987. Quality Criteria for Water 1986. US Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C.

US EPA. 1990a. "Water Quality Guidance for the Great Lakes System (Great Lakes Initiative)." U.S. Environmental Protection Agency, 40 CFR, Chapter 1, Part 132. http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_40/40cfr132_00.html

US EPA. 1990b. "Appendix D to Part 132 – Great Lakes Water Quality Initiative Methodology for the Development of Wildlife Criteria." U.S. Environmental Protection Agency, 40 CFR, Chapter 1, Part 132. http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_40/40cfr132_00.html

US EPA. 1992. "SAB Report: Review of Sediment Criteria Development Methodology for Non-Ionic Organic Contaminants." EPA-SAB-EPEC-93-002. U.S. Environmental Protection Agency, Science Advisory Board, Washington, D.C.

US EPA. 1993a. "Bioaccumulation Factor Portions of the Proposed Water Quality Guidance for the Great Lakes System." EPA-822-R-93-008, U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, D.C.

US EPA. 1993b. "Technical Basis for Deriving Sediment Quality Criteria for Nonionic Organic Contaminants for the Protection of Benthic Organisms by Using Equilibrium Partitioning." U.S. Environmental Protection Agency, Office of Water, EPA-822/R-93-011, pp 68, Washington, DC.

US EPA. 1994a. "Notice of Availability and Request for Comment on Sediment Quality Criteria and Support Documents." [OW-FRL-4827-2]. U.S. Environmental Protection Agency, *Fed. Regist*. 59(11):2652-2656, Jan. 18.

US EPA. 1994b. "Predicting Bioaccumulation of Sediment Contaminants to Fish." Draft Report, U.S. Environmental Protection Agency Region 5 Joint Health Effects Forum/In Place Pollutant Task Force Workgroup on Human Health Risks from Contaminated Sediments, Chicago, Illinois.

US EPA. 1995a. "Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories: Volume 1, Fish Sampling and Analysis." Second Edition, U.S. Environmental Protection Agency, EPA 823-R-93-002, Washington, D.C.

US EPA. 1995b. "Stay of Federal Water Quality Criteria for Metals; Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliance – Revision of Metal Criteria; Final Rules." U.S. Environmental Protection Agency, *Federal Register* 60(86):22228-22237

US EPA. 1995c. “Great Lakes Water Quality Initiative Technical Support Document for the Procedure to Determine Bioaccumulation Factors.” EPA-820-B-95-005, U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

US EPA. 1997a. “Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories: Volume 2, Risk Assessments and Fish Consumption Limits.” Second Edition, U.S. Environmental Protection Agency, EPA 823-B-97-009, Washington, D.C.

US EPA. 2000a. “Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California; Rule.” *Federal Register* 40 CFR Part 131, pp. 31682-31719. U.S. Environmental Protection Agency, Washington, D.C. May 18.

US EPA. 2000b. “Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment: Status and Needs.” U.S. Environmental Protection Agency, EPA-823-R-00-001, Washington, D.C. http://www.epa.gov/ost/cs/biotesting/

US EPA. 2000c. “Water Quality Criteria for Protection of Wildlife.” U.S. Environmental Protection Agency, 40 CFR, Chapter 1, Part 132. http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_40/40cfr132_00.html

US EPA. 2000d. “Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates.” Second Edition, U.S. Environmental Protection Agency, EPA/600/R-99/064, Washington, D.C.

US EPA. 2001a. “Water Quality Criteria for the Protection of Human Health: Methylmercury.” U.S. Environmental Protection Agency, Office of Water, EPA-833-F-01-001, Washington, D.C.

US EPA. 2001b. “Water Quality Criteria: Notice of Availability of Water Quality Criterion for the Protection of Human Health: Methylmercury.” U.S. Environmental Protection Agency, *Federal Register*, 66(5):1344-1359.

US EPA. 2002a. “McCormick & Baxter Creosoting Co. NPL Superfund Site,” US Environmental Protection Agency, Region 9, San Francisco, CA. http://yosemite.epa.gov/r9/sfund/overview.nsf/ef81e03b0f6bcdb28825650f005dc4c1/a33e349a42aae6d18825660b007ee68b?OpenDocument

US EPA. 2002b. “Ecotoxicity Database.” US Environmental Protection Agency, Office of Pesticide Programs, Washington D.C.

US EPA. 2002c. "Total Maximum Daily Loads for Toxic Pollutants San Diego Creek and Newport Bay, California." U.S. Environmental Protection Agency, Region 9, San Francisco, CA, June 14.

US EPA. 2002d. "Drinking Water MCLs." U.S. Environmental Protection Agency, Washington, D.C.

US EPA. 2002e. "Documents Related to Equilibrium Partitioning Sediment Guidelines (Sediment Quality Criteria)." URL: http://www.epa.gov/OST/pc/equilib.html

US EPA/US ACOE. 1991. "Evaluation of Dredged Material Proposed for Ocean Disposal -- Testing Manual." EPA-503-8-91-001, U.S. Environmental Protection Agency and U.S. Army Corps of Engineers, Washington, D.C.

US EPA/US ACOE. 1998. "Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. -- Testing Manual: Inland Testing Manual." EPA-823-B-98-004, U.S. Environmental Protection Agency and U.S. Army Corps of Engineers, Washington, D.C.

US FDA. 1984. "Shellfish Sanitation Interpretation: Action Levels for Chemicals and Poisonous Substances." U.S. Food and Drug Administration, Shellfish Sanitation Branch, Washington, D.C.

USGS. 1995a. Fact Sheet FS-152-95, U.S. Geological Survey, Sacramento, CA.

USGS. 1995b. Nonpoint Sources of Pesticides in the San Joaquin River, California: Input from Winter Storms 95-165, 1992-1993. U.S. Geological Survey, Sacramento, CA.

Veith, G. D. (coordinator); Carver, T. C., Jr.; Fetterolf, C. M.; Lee, G. F.; Swanson, D. L.; Willford, W. A.; and Zeeman, M. G. 1979. "Polychlorinated Biphenyls." In: A Review of the EPA Red Book: Quality Criteria for Water, American Fisheries Society, Bethesda, MD, pp. 239-246.

Many of the Lee, Jones, and Jones-Lee papers and reports are available from www.gfredlee.com.

Appendix A
Background Information Pertinent to Developing the US EPA and OEHHA Human Health Fish Tissue Screening Values

Cancer Risk of Group A Pesticides, PCBs, Dioxins and Furans (OEHHA)

Chemical Name	Inhalation Unit Risk (µg/cubic meter)$^{-1}$	Inhalation Slope Factor (mg/kg-day)$^{-1}$	Oral Slope Factor (mg/kg-day)$^{-1}$	US EPA Classification	IARC Classification	Comments
2,3,7,8-tetrachloro-dibenzo-p-dioxin and related compounds (TCDD)	38	130,000	130,000	--	2B**	
2,3,7,8-tetrachloro-dibenzofuran	3.8	13,000	--	--	--	
aldrin	0.0049	17	17	B2*	3	
chlordane	0.00034	1.2	1.3	B2*	2B**	Adopt USEPA value, geometric mean, LMS, surface area scaling. For Proposition 65 the number adopted in regulations for both routes of exposure is 1.3 (mg/kg day)^-1
DDT	0.000097	0.34	0.34	B2*	2B**	
dieldrin	0.0046	16	16	B2*	3	This value was used as the basis of the No Significant Risk Level that was adopted in Title 22, California Code of Regulations, Section 12705, Subsection b, for the purposes of the Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65).
endosulfan	--	--	--	--	--	
endrin	--	--	--	--	--	
heptachlor	--	4.1	4.1	B2*	--	Geometric mean, LMS, surface area scaling factor of body weight to the 0.67 power. For Proposition 65 the number in regulation for both inhalation and oral is 4.5
heptachlor epoxide	--	5.5	5.5	B2*	--	Geometric mean, LMS, surface area scaling factor of body weight to the 0.67 power. For Proposition 65 the number in regulation for both inhalation and oral is 9.1
hexachlorocyclo-hexane, alpha isomer	0.00077	2.7	2.7	B2*	2B**	
hexachlorocyclo-hexane, beta isomer	0.00043	1.5	1.5	C***	2B**	
hexachlorocyclo-hexane, gamma isomer (lindane)	0.00031	1.1	1.1	--	2B**	"Expedited" cancer potency. The No Significant Risk Levels based on these potency slopes are cited separately.
polychlorinated biphenyls (PCBs)	0.00057	2	5	B2*	2A****	

Cancer Risk of Group A Pesticides, PCBs, Dioxins and Furans (continued)

toxaphene	0.00034	1.2	1.2	B2*	2B**	This value was used as the basis of the No Significant Risk Level that was adopted in Title 22, California Code of Regulations, Section 12705, Subsection b, for the purposes of the Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65).

* US EPA Classification B2: Sufficient evidence in animals and inadequate or no evidence in humans
** IARC Classification 2B: The agent is possibly carcinogenic to humans
*** US EPA Classification C: Possible human carcinogen
**** IARC Classification 2A: The agent is probably carcinogenic to humans
-- Information not given
SOURCE: http://www.oehha.ca.gov/risk/ChemicalDB/start.asp

Oral RfD Summary for Selected Chemicals (US EPA – IRIS)

	Critical Effect	Experimental Doses	UF	MF	RfD
aldrin[1]	Liver toxicity Rat Chronic Feeding Study Fitzhugh et al., 1964	NOAEL: none LOAEL: 0.5 ppm diet (0.025 mg/kg/day)	1000	1	3E-5 mg/kg/day
chlordane[2]	Hepatic Necrosis Mouse 104-week oral study Khasawinah and Grutsch, 1989a	0.15 mg/kg-day NOAEL: 0.15 mg/kg-day LOAEL: 0.75 mg/kg-day	300	1	5E-4 mg/kg-day
p,p'-DDT[3]	Liver lesions 27-Week Rat Feeding Study Laug et al., 1950	NOEL: 1 ppm diet (0.05 mg/kg bw/day) LOAEL: 5 ppm	100	1	5E-4 mg/kg/day
dieldrin[1]	Liver lesions 2-Year Rat Feeding Study Walker et al., 1969	NOAEL: 0.1 ppm (0.005 mg/kg/day) LOAEL: 1.0 ppm (0.05 mg/kg/day)	100	1	5E-5 mg/kg/day
endosulfan[4]	Reduced body weight gain in males and females; increased incidence of marked progressive glomerulonephrosis and blood vessel aneurysms in males 2-Year Rat Feeding Study Hoechst Celanese Corp., 1989a ---------- Decreased weight gain in males and neurologic findings in both sexes 1-Year Dog Feeding Study Hoechst Celanese Corp.,1989a	NOAEL: 15 ppm [0.6 mg/kg-day (male); 0.7 mg/kg-day (female)] LOAEL: 75 ppm [2.9 mg/kg-day (male); 3.8 mg/kg-day (female)] ---------- NOAEL: 10 ppm 0.57 mg/kg-day (female) LOAEL: 30 ppm [1.9 mg/kg-day (female); 2.1 mg/kg-day (male)]	100	1	6E-3 mg/kg-day

Oral RfD Summary for Selected Chemicals (continued)					
endrin[5]	Mild histological lesions in liver, occasional convulsions Dog Chronic Oral Bioassay Velsicol Chemical Corporation, 1969	NOEL: 1 ppm in diet (0.025 mg/kg/day) LOAEL: 2 ppm in diet (0.05 mg/kg/day)	100	1	3E-4 mg/kg/day
heptachlor[1]	Liver weight increases increases in males 2-Year Rat Feeding Study Velsicol Chemical, 1955a	NOEL: 3 ppm diet (0.15 mg/kg/day) LEL: 5 ppm diet (0.25 mg/kg/day)	300	1	5E-4 mg/kg/day
heptachlor epoxide[5]	Increased liver-to-body weight ratio in both males and females 60-Week Dog Feeding Study Dow Chemical Co., 1958	NOEL: none LEL: 0.5 ppm (diet) (0.0125 mg/kg/day)	1000	1	1.3E-5 mg/kg/day
hexachlorocyclohexane, alpha, beta, delta and epsilon isomers	Data not available at this time				
hexachlorocyclohexane, gamma isomer (lindane)[6]	Liver and kidney toxicity Rat, Subchronic Oral Bioassay Zoecon Corp., 1983	NOAEL: 4 ppm diet [0.33 mg/kg/day (females)] LOAEL: 20 ppm diet [1.55 mg/kg/day (males)]	1000	1	3E-4 mg/kg/day
PCB Aroclor 1016[7]	Reduced birth weights Monkey Reproductive Bioassay Barsotti and van Miller, 1984; Levin et al., 1988; Schantz et al., 1989, 1991	NOAEL: 0.25 ppm in feed (0.007 mg/kg-day) LOAEL: 1 ppm in feed (0.028 mg/kg-day)	100	1	7E-5 mg/kg-day
PCB Aroclor 1248	The health effects data for Aroclor 1248 were reviewed by the U.S. EPA RfD/RfC Work Group and determined to be inadequate for the derivation of an oral RfD.	Derivation of an oral RfD for Aroclor 1248 is not recommended because a Frank Effect (death of an infant) was noted at the lowest dose tested in a sensitive animal species, rhesus monkeys (*Macaca mulatta*).			
PCB Aroclor 1254	Ocular exudate, inflamed and prominent Meibomian glands, distorted growth of finger and toe nails; decreased antibody (IgG and IgM) response to sheep erythrocytes Monkey Clinical and Immunologic Studies Arnold et al., 1994a,b; Tryphonas et al., 1989, 1991a,b	NOAEL: None LOAEL: 0.005 mg/kg-day	300	1	2E-5 mg/kg-day
toxaphene	Data not available at this time				

Oral RfD Summary for Selected Chemicals (continued)					
2,3,7,8-tetrachlorodibenzo-p-dioxin	Data not available at this time				
2,3,7,8-tetrachloro-dibenzofuran[8]	Hepatic lesions Mouse Subchronic Oral Study NTP, 1982	NOAEL: 2 mg/kg converted to 1.4 mg/kg/day on 5 days/7 days basis LOAEL: 4 mg/kg/day (rat)	1000	1	1E-3 mg/kg/day

RfD = Reference dose for chronic oral exposure
UF = Uncertainty factor
MF = Modifying factor
NOAEL = No observable adverse effects level
LOAEL = Lowest observable adverse effects level
Conversion Factors for Experimental Doses:
[1] 1 ppm = 0.05 mg/kg/day (assumed rat food consumption)
[2] 1 ppm = 0.15 mg/kg Bw-day (assumed mouse food consumption)
[3] Food consumption = 5% bw/day
[4] Actual dose tested
[5] 1 ppm = 0.025 mg/kg/day (assumed dog food consumption)
[6] Converted dose calculated from actual food consumption data
[7] Dams received a total average intake of 4.52 mg/kg (0.25 ppm) or 18.41 mg/kg (1 ppm) throughout the 21.8-month (654 days) dosing period. These doses are equivalent to 0.007 mg/kg-day and 0.028 mg/kg-day for the identified NOAEL and LOAEL respectively.
[8] 5 days/week feeding schedule
SOURCE: US EPA Integrated Risk Information System (IRIS) (http://www.epa.gov/iris)
See SOURCE for references listed in table.

Appendix B
Selected Tissue Residue Effects Data from Jarvinen and Ankley (1999)

Permission has been requested from SETAC Press

This data is available from http://www.epa.gov/med/databases/tox_residue.htm

Chemical	Test species	Life Stage	Test site and conditions	Exposure route and concentration	Test duration[1] (days)	Tissue analyzed	Tissue residue[2] (µg/g)	Effect	Comments
DDT	Cladoceran, *Daphnia magna* (Freshwater)	1st instar	Lab: Static	Water; 50 µg/L	1	Whole body	1150	Survival – Reduced 50%	
DDT	Mayfly, *Ephemera danica* (Freshwater)	Nymph	Lab: Flow-through	Water; 761 ng/L	9	Whole body	3.1	Survival – No effect	Residues = DDT + metabolite
DDT	Coho salmon, *Oncorhynchus kisutch* (Freshwater)	Embryo-Fry	Lab: Flow-through	Adult fish (Water, 50 µg/L)	1 (56)	Whole body (embryo)	1.09-2.76	Survival - Reduced	
DDT	Coho salmon, *Oncorhynchus kisutch* (Freshwater)	Embryo-Fry	Lab: Flow-through	Adult fish (Water, 50 µg/L)	1 (56)	Whole body (embryo)	0.55-0.66	Survival – No effect	
DDT	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Juvenile, 15 g	Lab: Flow-through	Diet; 1.0 mg/kg	140	Whole body	4.67	Survival, Growth-No effect	Radiotracer study; Residues = DDT + metabolites
DDT	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Sac fry - Fingerling	Lab: Flow-through	Maternal	90	Whole body	1.14-1.42	Survival – Reduced 90%	Residues = DDT + metabolite
DDT	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Egg-Fingerling	Lab: Flow-through	Maternal	90	Whole body	0.064-0.178	Survival – No effect	Residues = DDT + metabolite
DDT	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Egg-Fry	Lab: Flow-through	Maternal; Ovary, 3.47 µg/g	~60	Whole body (fry)	1.27	Survival (egg) – Reduced	Residues = DDT + metabolite
DDT	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Egg-Fry	Lab: Flow-through	Maternal; Ovary, 0.31-0.83 µg/g	~60	Whole body (fry)	0.15-0.30	Survival – No effect	Residues = DDT + metabolite
p,p'-DDT	Chinook salmon, *Oncorhynchus tshawytscha* (Freshwater)	Fingerling, 1.1 g	Lab: Flow-through	Diet; 100 mg/kg	40	Whole body	12.1-16.9	Survival – Reduced 94%	Residues = DDT + metabolite

p,p'-DDT	Chinook salmon, *Oncorhynchus tshawytscha* (Freshwater)	Fingerling, 1.1 g	Lab: Flow-through	Diet; 25 mg/kg	40	Whole body	11.4	Survival – No effect	Residues = DDT + metabolite
p,p'-DDT	Chinook salmon, *Oncorhynchus tshawytscha* (Freshwater)	Fingerling, 1.1 g	Lab: Flow-through	Diet; 100 mg/kg	5 (35)	Whole body	11.6	Survival – Reduced 53%	Residues = DDT + metabolite
p,p'-DDT	Chinook salmon, *Oncorhynchus tshawytscha* (Freshwater)	Fingerling, 1.1 g	Lab: Flow-through	Diet; 25 mg/kg	5 (35)	Whole body	2.2	Survival – No effect	Residues = DDT + metabolite
DDT	Brook trout, *Salvelinus fontinalis* (Freshwater)	Embryo-Fry	Lab: Flow-through	Adult fish; 2.8-7.6 mg/kg	(105)	Whole body (eggs and sac fry)	0.89-5.03	Survival – Reduced	Residues = DDT + metabolite
DDT	Brook trout, *Salvelinus fontinalis* (Freshwater)	Juvenile	Lab: Flow-through	Water; 3 ng/L	120	Whole body	1.92	Survival – No effect	Radiotracer study; Residues = DDT + metabolites
DDT	Brook trout, *Salvelinus fontinalis* (Freshwater)	Juvenile	Lab: Flow-through	Diet; 0.006 mg/kg	120	Whole body	25.6	Survival – No effect	Radiotracer study; Residues = DDT + metabolites
DDT	Brook trout, *Salvelinus fontinalis* (Freshwater)	Sac fry - Fingerling	Lab: Flow-through	Maternal	90	Whole body	0.464-0.485	Survival – Reduced 70 - 90%	Residues = DDT + metabolite
o,p'-DDT	Brook trout, *Salvelinus fontinalis* (Freshwater)	1 mo, 40 mg	Lab: Static, aerated	Diet; 0.128 µg/g (wet weight)	24 (24)	Whole body	0.008	Survival – No effect	
p,p'-DDT	Brook trout, *Salvelinus fontinalis* (Freshwater)	1 mo, 40 mg	Lab: Static, aerated	Diet; 0.248 µg/g (wet weight)	24 (24)	Whole body	0.009	Survival – No effect	
p,p'-DDT	Brook trout, *Salvelinus fontinalis* (Freshwater)	Juvenile	Lab: Flow-through	Injection; 7.5 µg/µL*	28 (28)	Whole body	1 – 5	Survival, Growth – No effect	Radiotracer study; *1/wk/4 wks
DDT	Brook trout, *Salvelinus fontinalis* (Freshwater)	Yearling-Adult	Field; Flow-through	Diet; 2 mg/kg/wk	156	Whole body	2.8-7.6	Survival, Growth – No effect	Residues = DDT + metabolite
DDT	Lake trout, *Salvelinus namaycush* (Freshwater)	Fry	Field; Flow-through	Adult fish; 50 µg/L	1 (30)	Whole body	2.93	Survival – Reduced	

DDT	Goldfish, *Carassius auratus* (Freshwater)	Adult	Lab: Flow-through	Water; 177.5 ng dm^{-3} Diet; 1.13 µg/g	13.6	Whole body	400	Survival – Reduced>80%	Radiotracer study; Residues = DDT + metabolites
DDT	Goldfish, *Carassius auratus* (Freshwater)	Adult	Lab: Flow-through	Water; 20.38 ng dm^{-3} Diet; 1.13 µg/g	38	Whole body	200	Survival – Reduced>20%	Radiotracer study; Residues = DDT + metabolites
DDT	Goldfish, *Carassius auratus* (Freshwater)	Adult	Lab: Flow-through	Water; 2.10 ng dm^{-3} Diet; 1.08 µg/g	58	Whole body	130	Survival – No effect	Radiotracer study; Residues = DDT + metabolites
DDT	Golden shiner, *Notemigonus crysoleucas* (Freshwater)	1.9 g	Lab: Renewal, 1 d	Water; 265 ng/L	15	Whole body	3.6[3]*	Survival – No effect	Radiotracer study; *Residue converted from dry to wet weight using factor given in paper; Residues = DDT + metabolites
DDT	Golden shiner, *Notemigonus crysoleucas* (Freshwater)	1.9 g	Lab: Renewal, 1 d	Diet; 309 ng	6	Whole body	0.025[3]*	Survival – No effect	Radiotracer study; *Residue converted from dry to wet weight using factor given in paper; Residues = DDT + metabolites
DDT	Fathead minnow, *Pimephales promelas* (Freshwater)	Juvenile-Adult	Lab: Flow-through	Diet; 45.6 µg/g	266	Whole body	57	Survival – Reduced 25%	Residues = DDT + metabolite
DDT	Fathead minnow, *Pimephales promelas* (Freshwater)	Juvenile-Adult	Lab: Flow-through	Water; 1.53 µg/L	266	Whole body	160	Survival – Reduced 50%	Residues = DDT + metabolite
DDT	Fathead minnow, *Pimephales promelas* (Freshwater)	Juvenile-Adult	Lab: Flow-through	Water; 0.35 µg/L	266	Whole body	40	Survival – No effect	Residues = DDT + metabolite
DDT	Fathead minnow, *Pimephales promelas* (Freshwater)	Juvenile-Adult	Lab: Flow-through	Water; 0.35 µg/L Diet; 45.6 µg/g	266	Whole body	86	Survival – Reduced 26%	Residues = DDT + metabolite
DDT	Fathead minnow, *Pimephales promelas* (Freshwater)	Juvenile-Adult	Lab: Flow-through	Water; 1.48 µg/L Diet; 45.6 µg/g	266	Whole body	209	Survival – Reduced 79%	Residues = DDT + metabolite

DDT	Fathead minnow, *Pimephales promelas* (Freshwater)	Larvae	Lab: Flow-through	Water or Water + Diet + Adult fish; 1.53 µg/L or 1.48 µg/L + 45.6 µg/g	5	Whole body	88-96	Survival – Reduced 100%	Residues = DDT + metabolite
DDT	Fathead minnow, *Pimephales promelas* (Freshwater)	Larvae	Lab: Flow-through	Adult fish; 209 µg/g	30	Whole body (embryo)	40.8	Survival – Reduced 81%	Larvae hatched and raised in clean water and fed clean foo Residues = DDT + metabolite
DDT	Mosquito fish, *Gambusia affinis* (Freshwater)	Not available	Lab: Statis	Water; 4 µg/L	16	Whole body	26.5	Survival – Reduced 50%	Fish had a total DDT residue level of 1.62 µg/g at the start the study; Residues = DDT + metabolites
DDT	Airbreathing fish, *Channa striatus* (Freshwater)	15 g	Lab: Static	Water; 360 µg/L*	4	Muscle	0.12-0.21	Survival – Reduced	Radiotracer study; *96 h LC50; Residues = DDT + metabolites
DDT	Green sunfish & pumpkinseed, *Lepomis cyanellus & L.. gibbosus* (Freshwater)	Juvenile	Field; Pools	Water; 1.02 µg/L	90	Whole body	24	Survival – Reduced – Death	Residues = DDT + metabolite
p,p'-DDD	Brook trout, *Salvelinus fontinalis* (Freshwater)	Juvenile	Lab: Flow-through	Injection; 7.5 µg/µL*	28 (28)	Whole body	1-5	Survival, Growth – No effect	Radiotracer study; *1/wk/4 wks
p,p'-DDD	Brook trout, *Salvelinus fontinalis* (Freshwater)	1 mo, 40 mg	Lab: Static, aerated	Diet; 0.054 µg/g (wet weight)	24 (24)	Whole body	0.008	Survival – No effect	
p,p'-DDE	Brook trout, *Salvelinus fontinalis* (Freshwater)	Juvenile	Lab: Flow-through	Injection, 7.5 µg/µL*	28 (28)	Whole body	1-5	Survival, Growth – No effect	Radiotracer study; *1/wk/4 wks
p,p'-DDE	Brook trout, *Salvelinus fontinalis* (Freshwater)	1 mo, 40 mg	Lab: Static, aerated	Diet; 0.0414 µg/g (wet weight)	24 (24)	Whole body	0.042	Survival – No effect	
DDE	Lake trout, *Salvelinus namaycush* (Freshwater)	Fry	Lab: Flow-through	Water; 32.7 ng/L Diet; 2.32 µg/g	176	Whole body	2.68	Growth – No effect	

DDE	Lake trout, *Salvelinus namaycush* (Freshwater)	Fry	Lab: Flow-through	Water; 1.8 ng/L Diet; 0.26 µg/g	176	Whole body	0.29	Survival – Reduced	
Dieldrin	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Juvenile	Lab: Flow-through	Water; 0.99 µg/L*	4	Whole body	5.65	Survival – Reduced > 50%	*96 h LC50 was 0.62 µg/L
Dieldrin	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Juvenile	Lab: Flow-through	Water; 0.15 µg/L	4	Whole body	0.548	Survival – No effect	
Dieldrin	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Juvenile, 15 g	Lab: Flow-through	Diet; 1.0 mg/kg	140	Whole body	2.13	Survival, Growth – No effect	Radiotracer study
Dieldrin	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Juvenile	Lab: Flow-through	Water; 0.08 µg/L Diet; 0.087 µg/g (wet weight)	112	Whole body	1.40	Growth – No effect	Fish fed at 4% of body weight
Dieldrin	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Juvenile	Lab: Flow-through	Water; 0.08 µg/L Diet; 0.087 µg/g (wet weight)	112	Whole body	0.36	Growth – No effect	Fish fed at 2% of body weight
Endosulfan (35% EC)	Fish, *Serranochromis* spp. (Freshwater)	Juvenile	Field; Natural river system	Water; 0.2-4.2 µg/L	3	Whole body	1.15	Survival – Reduced – Death	Residues in dead fish
Endosulfan (35% EC)	Fish, *Clarias* spp. (Freshwater)	Juvenile	Field; Natural river system	Water; 0.2-4.2 µg/L	3	Whole body	0.07	Survival – Reduced – Death	Residues in dead fish
Endosulfan (35% EC)	Fish, *Haplochromis* spp. (Freshwater)	Juvenile	Field; Natural river system	Water; 0.2-4.2 µg/L	3	Whole body	1.08	Survival – Reduced – Death	Residues in dead fish
Endosulfan (35% EC)	Fish, *Pseudocrenilabrus philander* (Freshwater)	Adult	Field; Natural river system	Water; 0.2-4.2 µg/L	3	Whole body	1.46	Survival – Reduced – Death	Residues in dead fish
Endosulfan (35% EC)	Fish, *Tilapia* + *Sarotherodon* spp. (Freshwater)	Juvenile	Field; Natural river system	Water; 0.2-4.2 µg/L	3	Whole body	1.10	Survival – Reduced – Death	Residues in dead fish
Endosulfan	Tilapia, *Tilapia aurea* (Freshwater)	Subadult	Lab: Static	Water; 2.4-4.4 µg/L	4	Muscle	0.115± 0.086*	Survival – Reduced – Death	*Standard deviation; Residues in dead fish
Endosulfan	Tilapia, *Tilapia aurea* (Freshwater)	Subadult	Lab: Static	Water; 2.4-4.4 µg/L	4	Muscle	0.078± 0.053*	Survival – No effect	*Standard deviation; Residues in surviving fish

Endrin	Golden shiner, *Notemigonus crysoleucas* (Freshwater)	Adult	Lab: Static	Water; 1500 µg/L	0.42	Whole body	55	Survival – Reduced 80%	Resistant fish
Endrin	Golden shiner, *Notemigonus crysoleucas* (Freshwater)	Adult	Lab: Static	Water; 1500 µg/L	0.04	Whole body	15.3	Survival – No effect	Resistant fish
Endrin	Golden shiner, *Notemigonus crysoleucas* (Freshwater)	Adult	Lab: Static	Water; 4 µg/L	0.33	Whole body	1.66	Survival – Reduced 100%	Susceptible fish
Endrin	Golden shiner, *Notemigonus crysoleucas* (Freshwater)	Adult	Lab: Static	Water; 4 µg/L	0.25	Whole body	1.20	Survival – Reduced 75%	Susceptible fish
Endrin	Golden shiner, *Notemigonus crysoleucas* (Freshwater)	Adult	Lab: Static	Water; 4 µg/L	0.17	Whole body	0.40	Survival – No effect	Susceptible fish
Endrin	Fathead minnow, *Pimephales promelas* (Freshwater)	Subadult, 120 d	Lab: Flow-through	Water; 0.19 µg/L	29	Whole body	4.3	Survival – No effect	Residue calculated from 29 d BCF determined in the study
Endrin	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling	Lab: Flow-through	Diet; 4.0 µg/g	198 (41)	Whole body	0.31	Survival, Growth – No effect	
Endrin	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling	Lab: Flow-through	Water; 0.5 µg/L	54	Whole body	0.7-1.0	Survival – Reduced – Death	
Endrin	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling	Lab: Flow-through	Water; 0.25 µg/L	54 (28)	Whole body	0.41	Survival – No effect	
Endrin	Bluegill, *Lepomis macrochirus* (Freshwater)	Not available	Lab: Flow-through	Water; 2 µg/L*	1	Whole body	0.3	Survival – Reduced	*24 h LC50; Residues in surviving fish
Endrin	Bluegill, *Lepomis macrochirus* (Freshwater)	Not available	Lab: Flow-through	Water; 2 µg/L*	1	Muscle	0.12	Survival – Reduced	*24 h LC50; Residues in surviving fish

Endrin	Bluegill, *Lepomis macrochirus* (Freshwater)	Not available	Lab: Flow-through	Water; 0.2 µg/L	1	Whole body	0.08	Survival – No effect	
Endrin	Bluegill, *Lepomis macrochirus* (Freshwater)	Not available	Lab: Flow-through	Water; 0.2 µg/L	1	Muscle	0.04	Survival – No effect	
Endrin	Largemouth bass, *Micropterus salmoides* (Freshwater)	Fingerling	Lab: Renewal, 5 d	Water; 0.1 µg/L	20	Whole body	0.0115	Survival – Reduced 40%	Residues in dead fish
Heptachlor	Fathead minnow, *Pimephales promelas* (Freshwater)	Larvae-Adult	Lab: Flow-through	Water; 0.86 µg/L*	276	Carcass, eviscerated	17.73	Survival – No effect	*100 percent mortality occurred at 1.84 µg/L, no tissue residue was reported
Hexachloro-cyclohexane (alpha-isomer)	Cladoceran, *Daphnia magna* (Freshwater)	<1 d	Lab: Renewal, 2 d	Water; 800 µg/L*	2	Whole body	250	Survival – Reduced – Death/Immobili-zation	*48 h EC50
Hexachloro-cyclohexane (alpha-isomer)	Cladoceran, *Daphnia magna* (Freshwater)	<1 d	Lab: Renewal, 2 d	Water; 50 µg/L	2	Whole body	2	Survival – No effect	
Hexachloro-cyclohexane (alpha isomer)	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Juvenile	Lab: Flow-through	Diet; 1250 mg/kg	84	Muscle	42	Survival, Growth – No effect	
Hexachloro-cyclohexane (alpha isomer)	Guppy, *Poecilia reticulata*	Juvenile	Lab: Renewal, 2 d	Water; 800 µg/L*	4	Whole body	170	Survival – Reduced – Death/Immobili-zation	*96 h EC50
Lindane	Midge, *Chironomus riparius* (Freshwater)	Larvae, 4th instar	Lab: Static	Water; 29.0 µg/L*	1	Whole body	0.046	Survival – Reduced 50%	Radiotracer study; *24 h LC5(pH 4
Lindane	Midge, *Chironomus riparius* (Freshwater)	Larvae, 4th instar	Lab: Static	Water; 11.2 µg/L*	1	Whole body	0.075	Survival – Reduced 50%	Radiotracer study; *24 h LC5(pH 6
Lindane	Midge, *Chironomus riparius* (Freshwater)	Larvae, 4th instar	Lab: Static	Water; 28.7 µg/L*	1	Whole body	0.072	Survival – Reduced 50%	Radiotracer study; *24 h LC5(pH 8
Pure grade lindane	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Yearling	Lab: Flow-through	Water; 26-100 µg/L	42	Muscle	2.3	Survival – Reduced – Death	Residues in dead fish

Pure grade lindane	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Yearling	Lab: Flow-through	Water; 10-20 µg/L	42	Muscle	0.8	Survival – No effect	Residues in surviving fish
Lindane	Brook trout, *Salvelinus fontinalis* (Freshwater)	Yearling-Adult	Lab: Flow-through	Water; 16.6 µg/L	261	Muscle	1.2	Survival – No effect	
Lindane	Brook trout, *Salvelinus fontinalis* (Freshwater)	Yearling-Adult	Lab: Flow-through	Water; 16.6 µg/L	261	Muscle	1.2	Growth – Reduced	
Lindane	Brook trout, *Salvelinus fontinalis* (Freshwater)	Yearling-Adult	Lab: Flow-through	Water; 8.8 µg/L	261	Muscle	0.77	Growth – No effect	
Lindane (99.9%)	Gudgeon, *Gobio gobio* (Freshwater)	Not available	Lab: Flow-through	Water; 142 µg/L	4	Muscle	0.59	Survival – Reduced 85%	
Lindane (99.9%)	Gudgeon, *Gobio gobio* (Freshwater)	Not available	Lab: Flow-through	Water; 72 µg/L	4	Muscle	1.07	Survival – Reduced 50%	
Lindane (99.9%)	Gudgeon, *Gobio gobio* (Freshwater)	Not available	Lab: Flow-through	Water; 28.5 µg/L	4	Muscle	0.013	Survival – No effect	
Lindane	Fathead minnow, *Pimephal*es *promelas* (Freshwater)	Juvenile-Adult	Lab: Flow-through	Water; 23.5 µg/L	304	Eviscerated carcass	9.53	Survival – Reduced	
Lindane	Fathead minnow, *Pimephal*es *promelas* (Freshwater)	Juvenile-Adult	Lab: Flow-through	Water; 9.1 µg/L	304	Eviscerated carcass	6.13	Survival – No effect	
Pure grade lindane	Roach, *Rutilus rutilus* (Freshwater)	28.9 g	Lab: Static	Water; 0.2-2 mg/L	5	Muscle	1.6-4.7	Survival – Reduced – Death	Residues in dead fish
Pure grade lindane	Roach, *Rutilus rutilus* (Freshwater)	Not available	Field; River*	Water; Not available	Not available	Muscle	1.6-2.0	Survival – Reduced – Death	*Fish kill, suspected lindane poisoning (see above)
Lindane	Bluegill, *Lepomis macrochirus* (Freshwater)	Juvenile-Adult	Lab: Flow-through	Water; 9.1 µg/L	735	Muscle	0.297	Survival, Growth – No effect	
Toxaphene	Brook trout, *Salvelinus fontinalis* (Freshwater)	Adult	Lab: Flow-through	Water; 502 ng/L	160	Whole body	8.0	Survival – Reduced – Death	
Toxaphene	Brook trout, *Salvelinus fontinalis* (Freshwater)	Adult	Lab: Flow-through	Water; 288 ng/L	160	Whole body	2.40	Survival – Reduced 50%; Growth – Reduced	

Toxaphene	Brook trout, *Salvelinus fontinalis* (Freshwater)	Adult	Lab: Flow-through	Water; 139 ng/L	160	Whole body	0.40	Survival, Growth – No effect	
Toxaphene	Brook trout, *Salvelinus fontinalis* (Freshwater)	Adult	Lab: Flow-through	Water; 68 ng/L	160	Whole body	0.40	Reproduction (egg viability) – Reduced	
Toxaphene	Brook trout, *Salvelinus fontinalis* (Freshwater)	Adult	Lab: Flow-through	Water; 39 ng/L	160	Whole body	0.20	Reproduction – No effect	
Toxaphene	Brook trout, *Salvelinus fontinalis* (Freshwater)	Embryo	Lab: Flow-through	Water; 68 ng/L	22	Whole body	0.90	Survival – Reduced	
Toxaphene	Brook trout, *Salvelinus fontinalis* (Freshwater)	Embryo	Lab: Flow-through	Water; 39 ng/L	22	Whole body	0.40	Survival – No effect	
Toxaphene	Brook trout, *Salvelinus fontinalis* (Freshwater)	Fry	Lab: Flow-through	Water; 39 ng/L	90	Whole body	0.40	Survival, Growth – Reduced	
Toxaphene	Fathead minnow, *Pimephales promelas* (Freshwater)	Adult	Lab: Flow-through	Water; 173 ng/L	295	Whole body	6.00-9.60	Survival, Reproduction – No effect	
Toxaphene	Fathead minnow, *Pimephales promelas* (Freshwater)	Adult	Lab: Flow-through	Water; 97 ng/L	295	Whole body	3.30	Growth – Reduced	
Toxaphene	Fathead minnow, *Pimephales promelas* (Freshwater)	Adult	Lab: Flow-through	Water; 54 ng/L	295	Whole body	1.00-2.70	Growth – No effect	
Toxaphene	Fathead minnow, *Pimephales promelas* (Freshwater)	Fry	Lab: Flow-through	Water; 173 ng/L	30	Whole body	2.80	Survival – No effect	
Toxaphene	Fathead minnow, *Pimephales promelas* (Freshwater)	Fry	Lab: Flow-through	Water; 54 ng/L	30	Whole body	1.00	Growth – Reduced	

Toxaphene	Fathead minnow, *Pimephales promelas* (Freshwater)	Fry	Lab: Flow-through	Water; 25 ng/L	30	Whole body	0.40	Growth – No effect	
Toxaphene	Fathead minnow, *Pimephales promelas* (Freshwater)	Embryo	Lab: Flow-through	Water; 173 ng/L	5	Whole body	1.00	Survival – No effect	
Toxaphene	Channel catfish, *Ictalurus punctatus* (Freshwater)	Adult	Lab: Flow-through	Water; 630 ng/L	100	Whole body	11.00	Survival, Growth, Reproduction – No effect	
Toxaphene	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fry	Lab: Flow-through	Water; 299 ng/L	30	Whole body	3.40	Survival, Growth – Reduced	
Toxaphene	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fry	Lab: Flow-through	Water; 129 ng/L	30	Whole body	1.90	Survival, Growth – No effect	
Toxaphene	Channel catfish, *Ictalurus punctatus* (Freshwater)	Embryo	Lab: Flow-through	Water; 630 ng/L	7	Whole body	4.40	Survival – No effect	
Toxaphene	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling, 5 g	Lab: Flow-through	Water; 106-475 ng/L	150	Whole body	1.8-14	Growth – Reduced	Fish fed diet containing 63 mg/kg vitamin C
Toxaphene	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling, 5 g	Lab: Flow-through	Water; 37-68 ng/L	150	Whole body	0.8-1.2	Growth – No effect	Fish fed diet containing 63 mg/kg vitamin C
Toxaphene	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling, 5 g	Lab: Flow-through	Water; 475 ng/L	150	Whole body	9.4	Growth – Reduced	Fish fed diet containing 670 mg/kg vitamin C
Toxaphene	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling, 5 g	Lab: Flow-through	Water; 106-218 ng/L	150	Whole body	3.3-4.6	Growth – No effect	Fish fed diet containing 670 mg/kg vitamin C
Toxaphene	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling, 5 g	Lab: Flow-through	Water; 475 ng/L	150	Whole body	4.0	Growth – No effect	Fish fed diet containing 5000 mg/kg vitamin C
Toxaphene	Mosquito fish, *Gambusia affinis* (Freshwater)	1.1 g	Lab: Static	Water; 2 mg/L	0.4	Whole body	0.68	Survival – Reduced – Death	Radiotracer study

Aroclor 1254	Coho salmon, *Oncorhynchus kisutch* (Freshwater)	Fingerling	Lab; Flow-through	Diet; 480 µg/g	265	Whole body	645-659	Survival – Reduced – Death	Radiotracer study; All fish die between 260 and 265 d of exposure
Aroclor 1254	Coho salmon, *Oncorhynchus kisutch* (Freshwater)	Fingerling	Lab; Flow-through	Diet; 48 µg/g	265	Whole body	54-57	Survival, Growth – No effect	Radiotracer study
Aroclor 1254	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Juvenile	Lab; Flow-through	Diet; 100 mg/kg	330	Whole body	81	Survival, Growth – No effect	
Aroclor 1254	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	14 wk, 0.77 g	Lab; Flow-through	Diet; 15 mg/kg	224	Whole body	8.5	Survival, Growth – No effect	
Aroclor 1254	Brook trout, *Salvelinus fontinalis* (Freshwater)	Immature	Lab; Flow-through	Diet; 7 doses at 1.65 mg/dose	18	Fillet	39	Survival, Growth – No effect	
Aroclor 1254	Brook trout, *Salvelinus fontinalis* (Freshwater)	Embryo	Lab; Flow-through	Adult fish; (Water, 0.2 mg/L)	21	Whole body	77.9	Survival – Reduced	
Aroclor 1254	Brook trout, *Salvelinus fontinalis* (Freshwater)	Embryo	Lab; Flow-through	Adult fish; (Water, control)	21	Whole body	<0.5	Survival – No effect	
Aroclor 1254	Brook trout, *Salvelinus fontinalis* (Freshwater)	Eyed egg-fry	Lab; Flow-through	Water; 3.1 µg/L	127	Whole body	125	Survival (fry) – Reduced 21%	
Aroclor 1254	Brook trout, *Salvelinus fontinalis* (Freshwater)	Eyed egg-fry	Lab; Flow-through	Water; 6.2 µg/L	127	Whole body	284	Survival (fry) – Reduced 50%	
Aroclor 1254	Brook trout, *Salvelinus fontinalis* (Freshwater)	Eyed egg-fry	Lab; Flow-through	Water; 13 µg/L	127	Whole body	419	Survival (fry) – Reduced 100%	
Aroclor 1254	Brook trout, *Salvelinus fontinalis* (Freshwater)	Eyed egg-fry	Lab; Flow-through	Water; 1.5 µg/L	127	Whole body	71	Survival – No effect	
Aroclor 1254	Brook trout, *Salvelinus fontinalis* (Freshwater)	Eyed egg-fry	Lab; Flow-through	Water; 1.5 µg/L	127	Whole body	71	Growth – Reduced	
Aroclor 1254	Brook trout, *Salvelinus fontinalis* (Freshwater)	Eyed egg-fry	Lab; Flow-through	Water; 0.69 µg/L	127	Whole body	31	Growth – No effect	

Aroclor 1254	Lake trout, *Salvelinus namaycush* (Freshwater)	Fry	Lab; Flow-through	Water; 327 ng/L Diet; 22.6 µg/g	176	Whole body	26.3	Growth – No effect	
Aroclor 1254	Lake trout, *Salvelinus namaycush* (Freshwater)	Fry	Lab; Flow-through	Water; 20.8 ng/L Diet; 1.05 µg/g	176	Whole body	1.53	Survival – Reduced	
Aroclor 1254	Lake trout, *Salvelinus namaycush* (Freshwater)	Fry	Lab; Flow-through	Water; 50 µg/L Diet; 0.72 µg/g	52	Whole body	2-4[3]	Survival, Growth – No effect	
Aroclor 1254	Fathead minnow, *Pimephales promelas* (Freshwater)	6 mo	Lab; Static	Water; 71.3 µg/L	12.5	Whole body	648-745	Survival – Reduced – Death	
Aroclor 1254	Fathead minnow, *Pimephales promelas* (Freshwater)	<24h-Adult	Lab; Flow-through	Water; 4.6 µg/L	240	Whole body	741-1253	Survival, Growth – No effect	
Aroclor 1254	Fathead minnow, *Pimephales promelas* (Freshwater)	<24h-Adult	Lab; Flow-through	Water; 1.8 µg/L	240	Whole body	83-553	Reproduction – Reduced	
Aroclor 1254	Fathead minnow, *Pimephales promelas* (Freshwater)	<24h-Adult	Lab; Flow-through	Water; 0.52 µg/L	240	Whole body	54-133	Reproduction – No effect	
Aroclor 1254	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling	Lab; Flow-through	Diet; 24 µg/g	193	Whole body	21	Survival, Growth – No effect	Radiotracer study
Aroclor 1248	Amphipod, *Gammarus pseudolimnaeus* (Freshwater)	Juvenile-Adult	Lab; Flow-through	Water; 5.1 µg/L	60	Whole body	552	Survival – No effect	
Aroclor 1248	Amphipod, *Gammarus pseudolimnaeus* (Freshwater)	Juvenile-Adult	Lab; Flow-through	Water; 5.1 µg/L	60	Whole body	552	Reproduction – Reduced	

Aroclor 1248	Amphipod, *Gammarus pseudolimnaeus* (Freshwater)	Juvenile-Adult	Lab; Flow-through	Water; 2.2 µg/L	60	Whole body	127	Reproduction – No effect	
Aroclor 1248	Fathead minnow, *Pimephales promelas* (Freshwater)	Embryo-Adult	Lab; Flow-through	Water; 3.0 µg/L	240	Whole body	190-360	Survival, Reproduction – No effect	Female fish had the highest residues
Aroclor 1248	Fathead minnow, *Pimephales promelas* (Freshwater)	Embryo-Adult	Lab; Flow-through	Water; 0.4 µg/L	240	Whole body	11-50	Growth – Reduced	Female fish had the highest residues
Aroclor 1248	Fathead minnow, *Pimephales promelas* (Freshwater)	Embryo-Adult	Lab; Flow-through	Water; 0.1 µg/L	240	Whole body	2.8-30.6	Growth – No effect	Female fish had the highest residues
Aroclor 1248	Channel catfish, Ictalurus punctatus (Freshwater)	Fingerling	Lab; Flow-through	Diet; 24 µg/g	193	Whole body	13	Survival, Growth – No effect	Radiotracer study
Aroclor 1242	Amphipod, *Gammarus pseudolimnaeus* (Freshwater)	Juvenile-Adult	Lab; Flow-through	Water; 26 µg/L	60	Whole body	409	Survival – Reduced – Death	
Aroclor 1242	Amphipod, *Gammarus pseudolimnaeus* (Freshwater)	Juvenile-Adult	Lab; Flow-through	Water; 8.7 µg/L	60	Whole body	246-387	Survival – No effect	
Aroclor 1242	Amphipod, *Gammarus pseudolimnaeus* (Freshwater)	Juvenile-Adult	Lab; Flow-through	Water; 8.7 µg/L	60	Whole body	246-387	Reproduction – Reduced	
Aroclor 1242	Amphipod, *Gammarus pseudolimnaeus* (Freshwater)	Juvenile-Adult	Lab; Flow-through	Water; 2.8 µg/L	60	Whole body	71-80	Reproduction – No effect	
Aroclor 1242	Amphipod, *Hyalella azteca* (Freshwater)	Young	Lab; Renewal, wkly	Water; 30 µg/L	105	Whole body	28.4	Survival, Growth, Reproduction – No effect	Radiotracer study

Aroclor 1242	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Egg-Fry	Lab; Flow-through	Adult fish; Not available	(30)	Whole body	2.7*	Survival – Reduced 75%*	*Possible mixture effect with 0.09 µg/g DDT complex
Aroclor 1242	Fathead minnow, *Pimephales promelas* (Freshwater)	6 mo	Lab; Static	Water; 89.6-138.2 µg/L	0.83	Whole body	1.28-20.5	Survival – Reduced – Death	LBB affected by time of death (see below)
Aroclor 1242	Fathead minnow, *Pimephales promelas* (Freshwater)	6 mo	Lab; Static	Water; 89.6-138.2 µg/L	6.3	Whole body	102-256	Survival – Reduced – Death	LBB affected by time of death (see above)
Aroclor 1242	Fathead minnow, *Pimephales promelas* (Freshwater)	<24 h-Adult	Lab; Flow-through	Water; 5.4 µg/L	255	Whole body	278-514	Survival, Growth – No effect	
Aroclor 1242	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling	Lab; Static, recirculating	Diet; 20 mg/kg	252	Whole body less stomach & contents	10.9-14.3	Survival, Growth – No effect	Reduction in growth during first 130 d
Aroclor 1260	Fathead minnow, *Pimephales promelas* (Freshwater)	6 mo	Lab; Static	Water; 28.6-57.3 µg/L	0.83	Whole body	0.36-10.0	Survival – Reduced – Death	LBB affected by time of death (see below)
Aroclor 1260	Fathead minnow, *Pimephales promelas* (Freshwater)	6 mo	Lab; Static	Water; 28.6-57.3 µg/L	12.5	Whole body	161-251	Survival – Reduced – Death	LBB affected by time of death (see above)
Aroclor 1260	Fathead minnow, *Pimephales promelas* (Freshwater)	Embryo-Adult	Lab; Flow-through	Water; 2.1 µg/L	240	Whole body	350-567	Survival, Growth, Reproduction – No effect	Female fish had the highest residues
Aroclor 1260	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling	Lab; Flow-through	Diet; 24 µg/g	193	Whole body	32	Survival, Growth – No effect	Radiotracer study
Aroclor 1268	Fathead minnow, *Pimephales promelas* (Freshwater)	6 mo	Lab; Static	Water; 2.72 µg/L	0.83	Whole body	0.45-4.53	Survival – Reduced – Death	
Aroclor 1232	Channel catfish, *Ictalurus punctatus* (Freshwater)	Fingerling	Lab; Flow-through	Diet; 24 µg/g	193	Whole body	14	Survival, Growth – No effect	Radiotracer study

PCBs, Mixture (Pentachloro-biphenyl mixture)	Zebra fish, *Brachydanio rerio* (Freshwater)	160-170 mg	Lab; Flow-through	Water; 0.7 mg/L	30 (30)	Whole body	4300	Survival – Reduced 83%	
2,3,7,8-Tetra-chlorodibenzo-p-dioxin (TCDD)	Cladoceran, *Daphnia magna* (Freshwater)	Adult	Lab; Model ecosystem	Water; 3.1 ng/L	32	Whole body	0.017	Survival – No effect	Radiotracer study
2,3,7,8-TCDD	Midge, *Chironomus tentans* (Freshwater)	Larvae-Adult	Lab; Renewal	Diet; 310 ng/g	35	Whole body	0.138	Survival, Growth, Reproduction – No effect	Radiotracer study
2,3,7,8-TCDD	Coho salmon, *Oncorhynchus kisutch* (Freshwater)	Young	Lab; Static/Flow-through	Water; 10.53 ng/L	4 (114)	Whole body	2.2	Survival, Growth – Reduced	
2,3,7,8-TCDD	Coho salmon, *Oncorhynchus kisutch* (Freshwater)	Young	Lab; Static/Flow-through	Water; 1.053 ng/L	4 (114)	Whole body	0.125	Survival, Growth – No effect	
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	35 g	Lab; Static/Flow-through	Water; 322 ng/L	0.25 (139)	Whole body	0.00065-0.00258	Growth – Reduced	Radiotracer study
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	35 g	Lab; Static/Flow-through	Water; 322 ng/L	0.25 (139)	Muscle	0.00026-0.00132	Growth – Reduced	Radiotracer study
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Juvenile	Lab; Flow-through	Diet; 2.3 µg/g	105	Whole body	1.38	Survival, Growth – Reduced	
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Juvenile	Lab; Flow-through	Diet; 2.3 ng/g	105	Whole body	0.0016	Survival, Growth – No effect	
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Fingerling	Lab; Flow-through	Diet; 0.494 ng/g	91	Whole body	0.00025	Survival, Growth – No effect	Radiotracer study
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Fingerling	Lab; Flow-through	Diet; 0.494 ng/g	91	Carcass	0.000315	Survival, Growth – No effect	Radiotracer study
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Egg-Sac fry - Fry	Lab; Flow-through	Injection; 0.230-0.488 ng/g egg*	(70)	Whole body (egg)	0.00023-0.00049*	Survival – Reduced 50%	*Range for four strains of fish not measured

2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Egg-Sac fry - Fry	Lab; Flow-through	Injection; 0.291 ng/g egg*	(70)	Whole body (egg)	0.000291*	Survival (sac fry) – Reduced	Radiotracer study; *Not measured
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Egg-Sac fry - Fry	Lab; Static/Flow-through	Water; 25 ng/0.3 L	2 (70)	Whole body (egg)	0.000279	Survival (sac fry) – Reduced	Radiotracer study
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Egg-Sac fry - Fry	Lab; Flow-through	Injection; 0.194 ng/g egg*	(70)	Whole body (egg)	0.000194*	Survival – No effect	Radiotracer study; *Not measured
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Fry, 0.38 g	Lab; Flow-through	Water; 176 pg/L	28	Whole body	0.00452	Survival – Reduced 50%	Radiotracer study
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Fry, 0.38 g	Lab; Flow-through	Water; 38 pg/L	28	Whole body	0.00098	Survival – No effect*	Radiotracer study; *Survival determined at 28 d
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Fry, 0.38 g	Lab; Flow-through	Water; 38 pg/L	28 (28)	Whole body	0.00098	Survival – Reduced 45%*	Radiotracer study; *Survival determined at 56 d
2,3,7,8-TCDD	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Fry, 0.38 g	Lab; Flow-through	Water; 38 pg/L	28	Whole body	0.00098	Growth – Reduced	Radiotracer study
2,3,7,8-TCDD	Brook trout, *Salvelinus fontinalis* (Freshwater)	Egg-Sac fry	Lab; Renewal, 12 h	Water; 8 ng/L	2 (78)	Whole body (egg)	0.185	Survival (sac fry) – Reduced	Radiotracer study
2,3,7,8-TCDD	Brook trout, *Salvelinus fontinalis* (Freshwater)	Egg-Sac fry	Lab; Renewal, 12 h	Water; 10 ng/L	2 (78)	Whole body (egg)	0.233	Survival (sac fry) – Reduced 50%	Radiotracer study
2,3,7,8-TCDD	Brook trout, *Salvelinus fontinalis* (Freshwater)	Egg-Sac fry	Lab; Renewal, 12 h	Water; 15-30 ng/L	2 (78)	Whole body (egg)	0.337-0.470	Survival (sac fry) – Reduced – Death	Radiotracer study
2,3,7,8-TCDD	Brook trout, *Salvelinus fontinalis* (Freshwater)	Egg-Sac fry	Lab; Renewal, 12 h	Water; 6 ng/L	2 (78)	Whole body (egg)	0.135	Survival (sac fry) – No effect	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Renewal, 12 h	Water; 25 ng/L	2 (78)	Whole body (egg)	0.11	Survival (sac fry) – Reduced – Death	Radiotracer study

2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Renewal, 12 h	Water; 15 ng/L	2 (78)	Whole body (egg)	0.072	Survival (sac fry) – Reduced 20%	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Renewal, 12 h	Water; 8.9 ng/L	2 (78)	Whole body (egg)	0.043	Survival (sac fry) – No effect	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Static	Water; Not available	2 (37)	Whole body (egg)	0.226	Survival (hatchability) – Reduced	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Static	Water; Not available	2 (37)	Whole body (egg)	0.065	Survival (sac fry) – Reduced 50%	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Static	Water; Not available	2 (37)	Whole body (egg)	0.055	Survival (sac fry) – Reduced	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Static	Water; Not available	2 (37)	Whole body (egg)	0.034	Survival (sac fry) – No effect	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Adult, female	Lab; Flow-through	Diet; 22 ng/g	77	Eggs	0.00031	Survival – No effect	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg	Lab; Flow-through	Maternal; 542 pg/g	(30)	Whole body	0.00023	Survival – Reduced	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg	Lab; Flow-through	Maternal; 353 pg/g	(30)	Whole body	0.00015	Survival – No effect	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Flow-through	Maternal; 337 pg/g	(120)	Whole body (egg)	0.000145	Survival (sac fry) – Reduced – Death	Radiotracer study

2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Flow-through	Maternal; 135 pg/g	(120)	Whole body (egg)	0.00006	Survival (sac fry) – Reduced 50%	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Flow-through	Maternal; 116 pg/g	(120)	Whole body (egg)	0.00005	Survival (sac fry) – Reduced	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Flow-through	Maternal; 53 pg/g	(120)	Whole body (egg)	0.000023	Survival – No effect	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; renewal, 12 h/Flow-through	Water; 100 ng/L	2 (120)	Whole body (egg)	0.00012	Survival (sac fry) – Reduced – Death	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; renewal, 12 h/Flow-through	Water; 62 ng/L	2 (120)	Whole body (egg)	0.00007	Survival (sac fry) – Reduced 50%	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; renewal, 12 h/Flow-through	Water; 40 ng/L	2 (120)	Whole body (egg)	0.00004	Survival (sac fry) – Reduced	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; renewal, 12 h/Flow-through	Water; 20 ng/L	2 (120)	Whole body (egg)	0.000034	Survival – No effect	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Sac fry	Lab; Flow-through	Injection; 154 pg/g egg*	(120)	Whole body (egg)	0.00015*	Survival (sac fry) – Reduced – Death	Radiotracer study; *Not measured
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Sac fry	Lab; Flow-through	Injection; 80 pg/g egg*	(120)	Whole body (egg)	0.00008*	Survival (sac fry) – Reduced 50%	Radiotracer study; *Not measured
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Sac fry	Lab; Flow-through	Injection; 55 pg/g egg*	(120)	Whole body (egg)	0.000055*	Survival (sac fry) – Reduced	Radiotracer study; *Not measured

2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Sac fry	Lab; Flow-through	Injection; 44 pg/g egg*	(120)	Whole body (egg)	0.000044*	Survival (sac fry) – No effect	Radiotracer study; *Not measured
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab;Renewal/ Flow-through	Water; 100 ng/L	2 (125)	Whole body (egg)	0.0004	Survival (sac fry) – Reduced – Death	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab;Renewal/ Flow-through	Water; 10 ng/L	2 (125)	Whole body (egg)	0.00004	Survival (sac fry) – Reduced	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab;Renewal/ Flow-through	Water; 1 ng/L	2 (125)	Whole body (egg)	<0.000015	Survival – No effect	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab; Flow-through	Injection; 0.044 ng/g egg*	(120)	Whole body (egg)	0.000044*	Survival (sac fry) – Reduced	Radiotracer study; *Not measured
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab; Flow-through	Injection; 0.033 ng/g egg*	(120)	Whole body (egg)	0.000033*	Survival – No effect	Radiotracer study; *Not measured
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab; Static/Flow-through	Water; 20 ng/L	2 (120)	Whole body (egg)	0.000055	Survival (sac fry) – Reduced	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab; Static/Flow-through	Water; 10 ng/L	2 (120)	Whole body (egg)	0.000034	Survival – No effect	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab; Static/Flow-through	Water; 40 ng/L	2 (120)	Whole body (egg)	0.000121	Survival (sac fry) – Reduced – Death	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab; Static/Flow-through	Water; 20 ng/L	2 (174)	Whole body (egg)	0.000055	Survival, Growth – Reduced	Radiotracer study

2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab; Static/Flow-through	Water; 10 ng/L	2 (174)	Whole body (egg)	0.000034	Survival, Growth – No effect	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry - Fry	Lab; Static/Flow-through	Water; >20 ng/L	2 (174)	Whole body (egg)	0.000065	Survival (sac fry) – Reduced 50%	Radiotracer study
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Flow-through	Injection; 80 pg/g egg*	(120)	Whole body (egg)	0.00008*	Survival (sac fry) – Reduced 50%	Radiotracer study; *Not measured
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Flow-through	Injection; 55 pg/g egg*	(120)	Whole body (egg)	0.000055*	Survival (sac fry) – Reduced	Radiotracer study; *Not measured
2,3,7,8-TCDD	Lake trout, *Salvelinus namaycush* (Freshwater)	Egg-Sac fry	Lab; Flow-through	Injection; 44 pg/g egg*	(120)	Whole body (egg)	0.000044*	Survival – No effect	Radiotracer study; *Not measured
2,3,7,8-TCDD	Carp, *Cyprinus carpio* (Freshwater)	Adult	Lab; Flow-through	Water; 60 pg/L	71	Whole body	2.2	Survival – Reduced	Radiotracer study
2,3,7,8-TCDD	Fathead minnow, *Pimephales promelas* (Freshwater)	Juvenile	Lab; Renewal, 4 d	Water; 1.7 ng/L*	28 (20)	Whole body	0.014[3]	Survival – Reduced – Death	Radiotracer study; *28 d LC5
2,3,7,8-TCDD	Japanese medaka, *Oryzias latipes* (Freshwater)	Embryo-Fry	Lab; Static	Water; 31.7 ng/L	14-17	Embryo, dechorio-nated	0.0033	Survival (fry) – Reduced – Death*	Radiotracer study; *Dead by 3 d posthatch
2,3,7,8-TCDD	Japanese medaka, *Oryzias latipes* (Freshwater)	Embryo-Fry	Lab; Static	Water; 13.2 ng/L	14-17	Embryo, dechorio-nated	0.0012	Survival – Reduced 60%	Radiotracer study
2,3,7,8-TCDD	Japanese medaka, *Oryzias latipes* (Freshwater)	Juvenile	Lab; Flow-through	Water; 8.9 pg/ml	12 (187)	Whole body	2.41	Survival – No effect	Radiotracer study
2,3,7,8-TCDD	Mosquito fish, *Gambusia affinis* (Freshwater)	Adult	Lab; Model ecosystem	Water; 3.1 ng/L	14	Whole body	0.01174	Survival – Reduced – Death	Radiotracer study

2,3,7,8-TCDD	Yellow perch, *Perca flavescens* (Freshwater)	Fingerling	Lab; Flow-through	Diet; 0.494 ng/g	91 (91)	Whole body	0.000143	Survival, Growth – No effect	Radiotracer study
2,3,7,8-TCDD	Yellow perch, *Perca flavescens* (Freshwater)	Fingerling	Lab; Flow-through	Diet; 0.494 ng/g	91 (91)	Carcass	0.000129	Survival, Growth – No effect	Radiotracer study
2,3,7,8-Tetrachlorodi-benzofuran (TCDF)	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Fry, 0.38 g	Lab; Flow-through	Water; 3.93 ng/L	28	Whole body	0.0093-0.0119	Survival – Reduced	Radiotracer study
2,3,7,8- TCDF	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Fry, 0.38 g	Lab; Flow-through	Water; 0.41 ng/L	28 (28)	Whole body	0.0025	Survival – No effect	Radiotracer study
2,3,7,8- TCDF	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Fry, 0.38 g	Lab; Flow-through	Water; 3.93 ng/L	28	Whole body	0.0093-0.0119	Growth – Reduced	Radiotracer study
2,3,7,8- TCDF	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Fry, 0.38 g	Lab; Flow-through	Water; 0.41 ng/L	28 (28)	Whole body	0.0025	Growth – No effect	Radiotracer study
2,3,7,8- TCDF	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Egg-Sac fry - Fry	Lab; Flow-through	Injection; 8.0 ng/g egg*	(70)	Whole body (egg)	0.008*	Survival (sac fry) – Reduced 70%	*Not measured
2,3,7,8- TCDF	Rainbow trout, *Oncorhynchus mykiss* (Freshwater)	Egg-Sac fry - Fry	Lab; Flow-through	Injection; 6.3 ng/g egg*	(70)	Whole body (egg)	0.0063*	Survival – No effect	*Not measured

1Test duration = exposure time. If organisms are placed in clean water and studied beyond the exposure period, this additional observation time is shown in parentheses.
2Wet weight
3Converted from dry weight to wet weight (0.2 factor[430]).

Adapted from Jarvinen & Ankley (1999). Presented with permission of SETAC Press.

Jarvinen, A. W. and Ankley, G. T., "Linkage of Effects to Tissue Residues: Development of a Comprehensive Database for Aquatic Organisms Exposed to Inorganic and Organic Chemicals," SETAC Press: Pensacola, FL (1999).

Appendix C
OCl Fish Tissue and Sediment Database

The letter designations on the left side of the data entry refer to an investigation letter code that is delineated in the footnote to the table. The maps presented in Figures 1(a) through 1(k) show the locations of sampling sites used in each of the investigations.

The aquatic organism OCl tissue data file is a separate Excel file. A copy of this file has been provided to the CVRWQCB, Sacramento, CA. This file is available via email upon request from G. Fred Lee at: gfredlee@aol.com.

Appendix D
USGS Sediment Chemical Characteristic Data

The Central Valley OCl sediment data base is a separate Excel file. This file is available upon request via email from G. Fred Lee at: gfredlee@aol.com. A copy of this file has been provided to the CVRWQCB, Sacramento, CA.